THIS REPORT HAS BEEN DELIMITED
AND CLEARED FOR PUBLIC RELEASE
UNDER DOD DIRECTIVE 5200.20 AND
NO RESTRICTIONS ARE IMPOSED UPON
ITS USE AND DISCLOSURE.

DISTRIBUTION STATEMENT A

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED.

262465

ALLEN APPLIED RESEARCH, INC.

130100

THE DOMAIN OF THE
GROUND EFFECT MACHINE

THE DETERMINATION OF PHYSICAL
AND OPERATING CHARACTERISTICS
OF MILITARY OVERLAND, AMPHIBIOUS
AND MARINE GEMS FROM WORLD-WIDE
ENVIRONMENTAL CRITERIA

Volume I

for

Office of Naval Research
Contract Number Nonr 3375(00)

August 1961

BOOZ·ALLEN APPLIED RESEARCH, INC.

CHICAGO
WASHINGTON

TABLE OF CONTENTS

TABLE OF CONTENTS - Continued

TABLE OF CONTENTS - Continued

TABLE OF CONTENTS - Continued

TABLE OF CONTENTS - Continued

INDEX OF FIGURES

I N D E X   O F   T A B L E S

INDEX OF TABLES Continued

SUMMARY

The total environmental aspects of Ground Effect Machines (GEMs) operated on a world-wide basis are examined in detail. The "natural" environment describing terrain, beaches, sea states and climate; the "induced" environment covering noise, spray and vibration; and the "combat" environment including vulnerability, infrared emanation and radar reflectivity are investigated sufficiently to determine their influence on the basic design requirements and operational parameters of the over-all GEM system.

Within the framework of the natural environmental elements a classification of GEMs is developed. This classification covers marine, overland, and amphibious GEM operations. In each of these categories vehicle sizes and operating heights and areas of utilization are included.

For all classes of GEMs the specific effects of the induced and combat environments are discussed. Finally, typical performance capabilities and equipment requirements based on the total operating environment are developed for each class of GEMs.

CONCLUSIONS

1. The elements of natural environment most significant for marine GEM operations are wave heights, sea ice, and wind speeds.

(a) GEM operations will generally be most favorable in latitudes below 30°. They will probably be operable from 90 to 100 per cent of the time in this region.

(b) GEM operations in oceanic areas in latitudes above 40° will be severely limited, and in some parts rendered impossible because of the prevalence of gale-force winds and high seas. In addition, superstructure icing or hummocked sea ice will have a significant influence on operations in some areas during the winter.

2. The elements of natural environment most significant for overland GEM operations are slopes of the surface terrain, widths and bank conditions of stream valleys, and heights of solid terrain obstacles.

(a) GEMs will have a significant advantage over other ground vehicles because of their capability to utilize stream valleys and inland waterways

as access routes. Vehicle widths, however, will be limited to 30 feet for operation on 75 per cent of the world's streams.

(b) A continuous operating height of two feet will be needed for general overland operations, and a minimum jump capability of four feet will be needed to cross walls, dikes, and rail embankments.

(c) Capability to surmount a five-foot vertical bank will be needed for access to and from stream valleys.

(d) A slope capability of 30 per cent at low speed, and 15 per cent at normal speed, will be needed for most overland operations.

(e) Operating speeds will be limited to about 30 to 40 knots on rivers because of control power requirements to traverse bends.

(f) Cross-country speeds will be limited by obstacles. Further study is required in this area.

(g) About 50 per cent of the over-all land area of the world is available for overland operations. The best area usability for a given size vehicle based on the present state-of-the-art is about 35 per cent of the world land area.

3. The elements of natural environment most significant for amphibious GEM operations are surf conditions, characteristics of beaches and coastal stream valleys, and coastal terrain obstructions.

(a) Operating heights will be determined primarily by the requirement to traverse the surf zone. Work done to date indicates that an operating height of four feet will allow operation on a year-round basis on 70 per cent of the world's coasts (storm conditions not included). Full-scale experimental data are needed to justify final design parameters.

(b) Operating heights for clearance of land obstacles will be two feet for normal operations with a four-foot jump capability.

(c) Slopes of beaches are not generally over 15 per cent, but beach widths limit lateral dimensions of the vehicle to about 50 feet for unloading above the high water line on the majority of the world's beaches.

(d) Coastal stream valleys provide an important inland access route for GEMs. Vehicle widths will be limited to 40 feet for operation on 70 per cent of coastal streams.

(e) About 70 per cent of the world's coastline, excluding Antarctica, Greenland, and the North American Arctic Islands above 77° North Latitude, is accessible to GEM amphibious operations. About 30 per cent of the world's near-coastal land areas are accessible to GEM operations inland via stream valleys or over the beach. About 30 per cent of the world's coasts are not suitable for GEM operations.

4. The major limitations imposed on GEM operations by the induced environments and combat environments are as follows:

(a) Noise Levels

(1) The noise level anticipated in and around the GEM is such that conversation will require raised voices and probably shouting. For continuous and effective operation, ear protection and communications equipment similar to that used in aircraft operations will be highly desirable.

(2) The noise level at appreciable distances from a GEM will depend largely on the design of the vehicle intake and exhaust systems.

If the low frequency portion of the noise spectrum can be attenuated at the vehicle, detection will be difficult beyond 1000 yards. If this is not feasible, detection will probably start at about 2500 yards.

(b) <u>Visibility</u>

(1) The visibility from a GEM will be severely limited when the vehicle is hovering or operating at low speed over loose surfaces, such as sand, gravel, dry soil, snow, and water. This situation improves rapidly as forward speed is increased, although visibility rearwards may still be a problem.

(2) The cloud of particles surrounding a GEM at hover or low speed, or tailing a GEM at high speed, may serve as a very distinct signature of its presence.

(c) <u>Reingestion of the Momentum Curtain Air, and Entrained Particles</u>

The momentum curtain air discharged under the vehicle periphery recirculates to some degree in the hover condition and at low speeds. This recirculating air stream carries with it

particles of surface materials, that pass through the lift system and the power unit, with the following consequences:

(1) Erosion of the engine and lift system rotors and stators may occur. Erosion is worst for sand-type materials. Power losses of approximately 15 per cent have been experienced on helicopters and can be anticipated on GEMs.

(2) Corrosion of the engines and lift system and the vehicle surface will occur in all over-water operations. This is most serious in a salt-water environment. Salt encrustation of rotor and stator blading of the engine and lift systems will cause loss in power of up to 20 per cent and increase in fuel consumption of approximately 1.5 per cent.

(3) Snow and ice will accumulate on the vehicle year-round in Arctic and Antarctic operations and in the winter months in the northern two-thirds of Asia, Europe, and North America. This accumulation causes a loss of vehicle performance. When subfreezing air temperatures are encountered, the mist enshrouding

the machine will freeze on contact, forming a heavy load of glaze ice.

(4) The recirculation and general disturbance of surface material will make servicing of the vehicle difficult while it is in operation. and will require protective clothing and equipment for ground personnel under some operational conditions.

5. On the basis of performance capability and utility, as determined by the world-wide natural environmental factors, and vulnerability in a military combat situation, a rough assessment of the relative merit of each machine classified for overland, amphibious and marine operations indicates the following results:

(a) The GEM having the greatest potential for overland operations is a vehicle with a planform of 30 feet by 60 feet, an operating height of three feet, and a jump capability of six feet.

(b) The GEM having the greatest potential for amphibious operations is a vehicle with a planform of 50 feet by 100 feet, a normal operating height of three feet, a maximum operating height of five feet, and a jump capab... of six feet.

(c) The GEM having the greatest potential for marine operations in the open ocean is a vehicle with a planform of 50 feet by 100 feet, a normal operating height of 2.5 feet and a maximum operating height of four feet.

(d) The GEM having the greatest potential for marine operations in inland waterways and coastal waters is a vehicle having a planform of 30 feet by 60 feet, a normal operating height of 1.5 feet, and a maximum operating height of 2.5 feet.

6. Special equipment will be required for each environment in order that missions may be accomplished efficiently, and maintenance be reduced to a minimum. Such equipment must be determined for the particular environmental conditions of the desired missions for a specific vehicle, and will demand additional power requirements or a reduction in over-all performance.

RECOMMENDATIONS

1. The environmental framework for Ground Effect Machines developed in this study should be applied to all future studies and programs on military GEM hardware.

2. Full scale tests should be conducted on GEM operations through the surf zone. Specific data are needed on the required relation between surf conditions and vehicle size and operating height.

3. Experimental data should be obtained on the maneuverability requirements for GEMs in overland cross-country operations. In addition, studies of GEM maneuverability system improvements should be initiated.

4. Further study is recommended in the following areas associated with the induced and combat environments of GEMs:

(a) Noise

Data are required on the frequency spectrum of GEM noise and the effect of different operating conditions and environments on the noise level.

(b) Flow Field

Further study of the GEM flow field is required, particularly of the relationship between

the problems of reingestion, visibility, and signature, and GEM mission characteristics. In addition, development of advanced lift systems and other devices for reducing the effects of the GEM flow field should be studied.

(c) Dynamic Loads

Accurate and reliable analytical data should be developed for the dynamic stressing of GEMs, particularly in over-water operations.

(d) Icing

Specific environmental data on GEM icing problems should be obtained, and development of suitable de-icing equipment should be initiated.

(e) Corrosion and Erosion

Methods and materials for reducing corrosion and erosion in GEM power plants and lift systems should be developed.

(f) Navigation Equipment

Navigation equipment particularly suited to GEMs should be developed. This includes a collision warning or obstacle avoidance radar, and simple course guidance presentation.

(g) Radar Cross-Section

Basic design criteria should be developed for minimizing the radar cross-section of military GEMs, particularly for over-water operation.

5. Optimization of vehicle performance and design should be carried out within the environmental framework developed for each category of operations - overland, amphibious, and marine.

INTRODUCTION

The significant developments of the past few years relative to the ground effect phenomenon have established the Ground Effect Machine (GEM) as a practical transportation vehicle when certain operational limitations are accepted. It is the purpose of this report to outline the various operational limitations for military GEMs and to present features considered essential in military applications.

Since military vehicles and their components are required to operate throughout a wide range of environments, their design must prevent functional, operational, and maintenance difficulties caused by extremes of these environments. In world-wide operation of GEMs these vehicles are subjected to the following three types of environment:

(1) Natural environment, such as climate, terrain, vegetation, sea states, beach slopes and condition, sea approaches to coasts, and natural and man-made obstacles.

(2) Induced environment, such as component-generated high temperatures, static electricity, vibration, shock, acceleration, explosive vapors, sound, dust, spray, and exhaust gases.

(3) Combat environment, including the elements of detection, vulnerability, protection against damage, and field repairs.

Determination of the influence of environmental conditions on the engineering design and military utilization of GEMs is a necessary first step in the determination of structural and other essential design criteria. An evaluation of environment is also essential to a realistic appraisal of the potential of the GEM for military operations.

The natural environment of the GEM includes all the areas and conditions under which this type of vehicle is required to be operated. This will encompass not only the world-wide variety of terrains, but also the full scale of climate variations, including the specific influences of temperature, humidity, wind, and icing conditions.

Average sea-state conditions vary with the seasons and location. For obvious reasons, designs for military applications must consider the worse conditions anticipated. Depending on the current and ocean area involved, sea conditions usually affect breakers and beaching operations in direct proportion, and indicate parameters which must be considered in the design of marine and amphibious vehicles.

Overland operating environment includes the nature of the terrain and its surface material -- ranging from snow, sand, and marsh to brush areas, ditches and ravines, and built-up areas. An important consideration for military operations is the terrain slope which has a direct influence on the power requirements. For some cases, consideration must be given to means of quickly clearing wooded areas and other terrains which offer obstructions to GEM operations.

Climatic influences have a strong effect on GEM vehicles. The effects of temperature and humidity on the internal flow system and power plant must be known. In the presence of winds, provision must be made for adequate control of power to maintain the desired track.

<u>The induced environment</u> of the GEM is the effect created by the operation of the vehicle, on itself and on the surrounding area, including personnel within or close to the vehicle. Two of the more prominent problem areas under this heading are the total effects of the downwash disturbance field and noise levels and attenuation.

Further analysis of the downwash disturbance problem is vital to the development of an operational military GEM. This problem assumes critical proportions for low-speed and hovering operation, where the vehicles are enveloped in dust or spray. One manifestation of the

downwash disturbance is potential re-ingestion into the lift/propulsion system, reducing the efficiency of the system and leading to component damage. At low speeds the downwash disturbance will significantly reduce the visibility of the driver. Under these circumstances, the GEM must be operated with considerable caution, or by reference to instruments if the dust or spray is not controlled.

The noise generated by the military GEM may have adverse effects on personnel inside the vehicle and in proximity to the vehicle during hover and cruise flight. Noise may also contribute to operator fatigue, early structural fatigue and malfunction of electronic equipment. The noise spectrum of the GEM vehicle must be ascertained and compared with military specifications for acceptable noise levels in order to determine areas where suppression is required, or where operating limitations must be imposed.

The combat environment envisioned for the GEM is similar to that for most other combat vehicles. Two important problems of this environment are avoidance of detection and protection against enemy fire. The suppression of noise and infrared emanation assumes a great importance in the combat environment. Radar detection is not a major problem since the vehicle is operated close to the surface.

The vulnerability of the GEM to damage by enemy fire must also be analyzed, particularly the effect of damage to the lift system; in this case, a requirement for armor plating or use of self sealing components in certain areas of the vehicle might be a consideration.

Associated with the combat environment is the requirement for development of maintenance concepts for this vehicle. Particularly, consideration must be given to field repair of damage to the lift system. A simplified "patch kit" may be found suitable for this kind of work. Possibly, provision can be made for closing a damaged section and maintaining operation with an incomplete jet "curtain." There is also an obvious problem in lifting the weight of the vehicle to work on the underside components.

The purpose of this report, therefore, is to present the total environmental picture surrounding the Ground Effect Machine operated on a world-wide basis and to classify a range of vehicles with operational capabilities in these environments.

The report is assembled in four chapters, with three detailed appendices of data from which the chapters were constructed.

Chapter I - The World-wide Environment and the Ground Effect Machine, presents a summary and discussion of the natural environments of operational Ground Effect Machines on a world-wide basis. Climatic and physical features of maritime, continental, and coastal environments are included.

Chapter II - Classification of Military Ground Effect Machines, outlines families of vehicles for marine, overland, and amphibious operations, corresponding to the three realms of natural environments discussed in Chapter I. Operational utilization potentials are tabulated for each class of vehicles.

Chapter III - Effects of the Induced and Combat Environments on Military Ground Effect Machines, describes the elements of these environments and their influence on GEM design and equipment requirements.

Chapter IV - Effects of Size and Operational Utilization on the Selection of a Military Ground Effect Machine, presents a tabulation of basic performance parameters developed for the vehicles classified in Chapter II, and a summary of the military operations appropriate to each class. Equipment requirements based on the total operating environment are included.

The Bibliography includes the source materials used in the preparation of this report.

The Appendices to this report (bound separately as Volume II) include tabulations of the background data for the world-wide natural environments. Appendix A includes Climatic and Oceanographic Data, Appendix B includes Natural Features of Continental Environments, and Appendix C includes Natural Features of Coastal Environments. Notes on the sources and use of the tabular materials are included in the appendices.

Because much of the background data have been assembled from classified sources, Appendix B and Appendix C are classified CONFIDENTIAL.

I. THE WORLD-WIDE ENVIRONMENT AND THE GROUND EFFECT MACHINE

1. INTRODUCTION

This chapter covers the elements of natural environment which affect the design and performance parameters of Ground Effect Machines. Since very little data have previously been developed for the effects of natural environment on the GEM, the material of this chapter is based on a review of fundamental characteristics of the world-wide natural environment with consideration primarily of the features which would have presumed effect on GEM operations.

(1) State-of-the-Art Assumptions

In order to provide a realistic framework for the study, generalized limits must be set on the available and projected state-of-the-art for Ground Effect Machines. These should not be considered as arbitrarily specific characteristics of vehicles but rather as general frames of reference. The Ground Effect Machines discussed in this report include annular jet and plenum type vehicles likely to be available based on the state-of-the-art now existing and including anticipated developments through 1970.[29, 32, 37, 39] The following characteristics have been assumed:

1. Vehicles may be either full annular jet or plenum chamber types or may utilize sidewalls or skegs.

2. The study is limited to vehicles capable of carrying men and material in off-road operation over land and water and in amphibious operations. Special-use devices such as pallet handling equipment and loaders are not included.

3. The propulsion and lift air requirements will be met through fans, compressors, or ejectors, powered by automotive, aircraft, and marine type engines.

4. Vehicle sizes, operating heights, and power requirements, discussed in Chapters II and IV, reflect practical applications of the GEM state-of-the art, including anticipated gradual advances.

5. More advanced concepts (channel GEM, GETOL, full ram wing, etc.) are not included.

Areas where GEM operations based on the above state-of-the-art would be very difficult are expressed as "un-GEM-able". They include:

1. Areas with steady slopes over 30 per cent.

2. Dense forests of mature timber (8 to 12 inches in diameter and greater) -- brush wood and young forests may be cleared.

3. Areas of large surface discontinuities; e.g., networks of ditches over 20 feet wide and 10 feet deep, congested built-up area (city centers), canyons in arid countries over 20 feet deep with wall slopes greater than 100 per cent (45°), waterfalls over 10 feet in height.

In all other areas, some kind of GEM is presumed to have operational capability. Performance and size requirements are developed in Chapters II and IV. In some cases even within the limits of technical suitability, these requirements will be such as to make the GEM quite unattractive for military operations.

The data on natural environment presented herein are developed for the world on an area basis and are not intended to indicate requirements for any specific operation. Even in "un-GEM-able" areas, there will be some feasible, and perhaps very advantageous, operations, e.g., a river valley in a mountainous area.

Conversely, in an area which is mostly suitable for GEM operations there may be "un-GEM-able" features or features requiring special design and performance characteristics.

(2) Introduction to World-Wide Environments

Since the GEM has apparent capabilities as an overwater and amphibious vehicle, and since the diversity of characteristics between land and marine operations is significant, world-wide environments have been divided into three categories:

1. Maritime environments for marine operations.
2. Coastal environments for amphibious operations.
3. Continental environments for overland operations, including use of inland waterways.

The world area has been studied in terms of these three categories of natural environment, and data presented herein represent the generalized characteristics of these environments. Inasmuch as the Ground Effect Machine has very different capabilities from other military vehicles, it has been necessary to develop the environmental material on a fundamentally new set of characteristics. In each case, the ... available

reference material was reviewed and significant environmental data derived and summarized. (References are listed in the Bibliography.)

In the presentation of environmental data, the following breakdown of the world-wide surface has been used:

1. Maritime environments are discussed in terms of the major ocean areas including adjoining seas.

2. Coastal environments are discussed in terms of coasts of continents facing on the various oceans.

3. Continental environments are discussed in terms of continental land masses, including Antarctica. In the discussion of physical features, the Eurasian land mass has been divided for convenience into U.S.S.R., Europe excluding U.S.S.R., and Asia excluding U.S.S.R., following the arrangement now being adopted by geographers.

The environmental material is presented, in this chapter, in tabulations of nat[illegible] environmental features with illustrative text material. Complete

detailed environmental data developed during the study are included in the Appendices (Volume II). Although comprehensive, these data are not to be considered as planning materials for GEM operation in a specific area, but only as illustrative of the general features in that area.

2. CLIMATIC AND OCEANOGRAPHIC FEATURES

(1) Climatic Classifications

The natural environment that will influence the design and operation of the Ground Effect Machine may be divided into three broad categories, maritime, coastal (or transitional) and continental. Contained within each of these categories is a wide variety of climates and either physical or oceanographic characteristics. This variety makes necessary a division of each category into zones having relatively homogeneous characteristics.

The coastal and continental environments may be divided into regions with homogeneous climatic characteristics, with uniform physical features, or according to political boundaries. Political boundaries usually do not coincide with natural boundaries, hence they are used only when knowledge of distribution of characteristics within each country becomes important.

There are few areas on the earth where a sharp boundary between climatic zones can be delineated Rather, there are transition zones which, in a more

detailed subdivision, might themselves be classified as zones. Since too much detail masks the essential broad features, the zone breakdown used in this study has been chosen so that boundaries are located along lines of maximum rate of transition and the number of zones is held to a reasonable number.

The coastal zone classifications specified by Bailey[36] meet the requirements of this study. Bailey used vegetation types as the primary basis for determining his zone classifications and boundaries. He confirmed these by developing statistics on temperature and precipitation magnitudes and distributions with the seasons for each classification. These classifications and characteristics are listed in Table 1. Zone boundaries for both coastal and continental zones are shown in Figures 1 to 7.

The Critchfield climatic classification[4] for continental areas appears to be most suitable for purposes of this study. It is in good agreement with, and is largely based upon the classifications developed by Koeppen[8], and others. Geography, temperatures, and precipitation with their seasonal variation and related vegetation cover provided the basis for Critchfield's determination of zone boundaries. His

TABLE 1

Climatic Characteristics Related to Coastal Landscapes

(After Bailey)

Class No.	Climatic Type: Name (and per cent of world coastline including Antarctica)	Temperature (°F): Mean Maximum, Warmest Month	Temperature (°F): Mean Minimum, Coldest Month	Precipitation: Mean Annual, (Inches)	Precipitation: Mean Annual, Days 0.01 in.	Winter Concentration of Precipitations**	Corresponding Vegetation Types	
1	Rainy Tropical (20%)	86-8[illegible]	67-73	78-122	134-185	14-49	Malayan	(evergreen rain forest)
2	Subhumid Tropical (10%)	86-92	59-70	41- 55	61-114	17-38	Nicaraguan	(deciduous or monsoon forest)
							Timoran	(savanna forest or woodland)
							Visayan	(tropic grassland)
3	Warm Semiarid ([illegible]%)	89-94	55-66	21- 28	42- 60	9-40	Tampicoan	(thorn forest, thorn scrub)
							Tamaulipan	(desert savanna), wetter parts
4	Warm Arid (5%)	92-98	51-68	5- 10	10- 32	36-94	Tamaulipan	(desert savanna), drier parts
							Sonoran	(subtropic desert)
							Tripolian	(short grass; desert grass)
5	Hyperarid (4%)	75-93	48-57	< 2	1- 4	42-100	Atacaman	("barren" desert)
6	Rainy Subtropical (6%)	84-89	42-49	45- 58	93-142	29-49	Kyushun	(warm temperate rain forest)
							Argentinean	(prairie)
7	Summer-dry Subtropical (7%)	80-87	43-48	17- 27	54-103	74-87	Mediterranean	(sclerophyll woodland and scrub)
8	Rainy Marine (1%)	62-68	39-44	43- 81	166-187	51-69	Tasman	(subantarctic forest)
9	Wet-winter Temperate (2%)	62-72	32-42	39- 67	120-192	67-78	Oregonian	(conifer forest)
10	Rainy Temperate (9%)	58-81	19-35	26- 44	127-188	41-54	Virginian	(mixed deciduous and conifer forest)
11	Cool Semiarid (1%)	67-87	26-49	12- 21	45- 87	37-52	Patagonian	(cold desert), wetter parts
12	Cool Arid ([illegible]%)	70-78	34-45	4- 6	24- 41	54-88	Patagonian	(cold desert), drier parts
13	Subpolar ([illegible]%)	59-73	-10- 9	18- 41	106-184	32-50	Alaskan	(taiga forest)
14	Polar (2[illegible]%)	48-55	-30- 8	7- 26	91-131	30-49	Aleutian	(tundra and polar barrens)

*Each pair of numerals in the body of the table refers to data from climatic stations at the 25th and 75th percentiles of the frequency distribution appropriate to the climatic type and element. As only long-period means have been entered into the frequency distributions, the data in the table show the spread in average conditions of climate in the most representative parts of the several climatic regions. Because approximately equal spacing was employed in the station network, it is also true that the data illustrate, for a given climatic type, conditions in about 50 per cent of the aggregate length of coastline affected by that climatic type.

**The winter concentration of precipitation is defined as the percentage of the mean annual total that falls in the winter half-year, October through March in the Northern Hemisphere, April through September in the Southern Hemisphere. The computation was not carried out for those places where the difference between the mean monthly temperatures of the warmest and coldest month was less than 5° F.

FIGURE 1
Climatic Zones of Europe

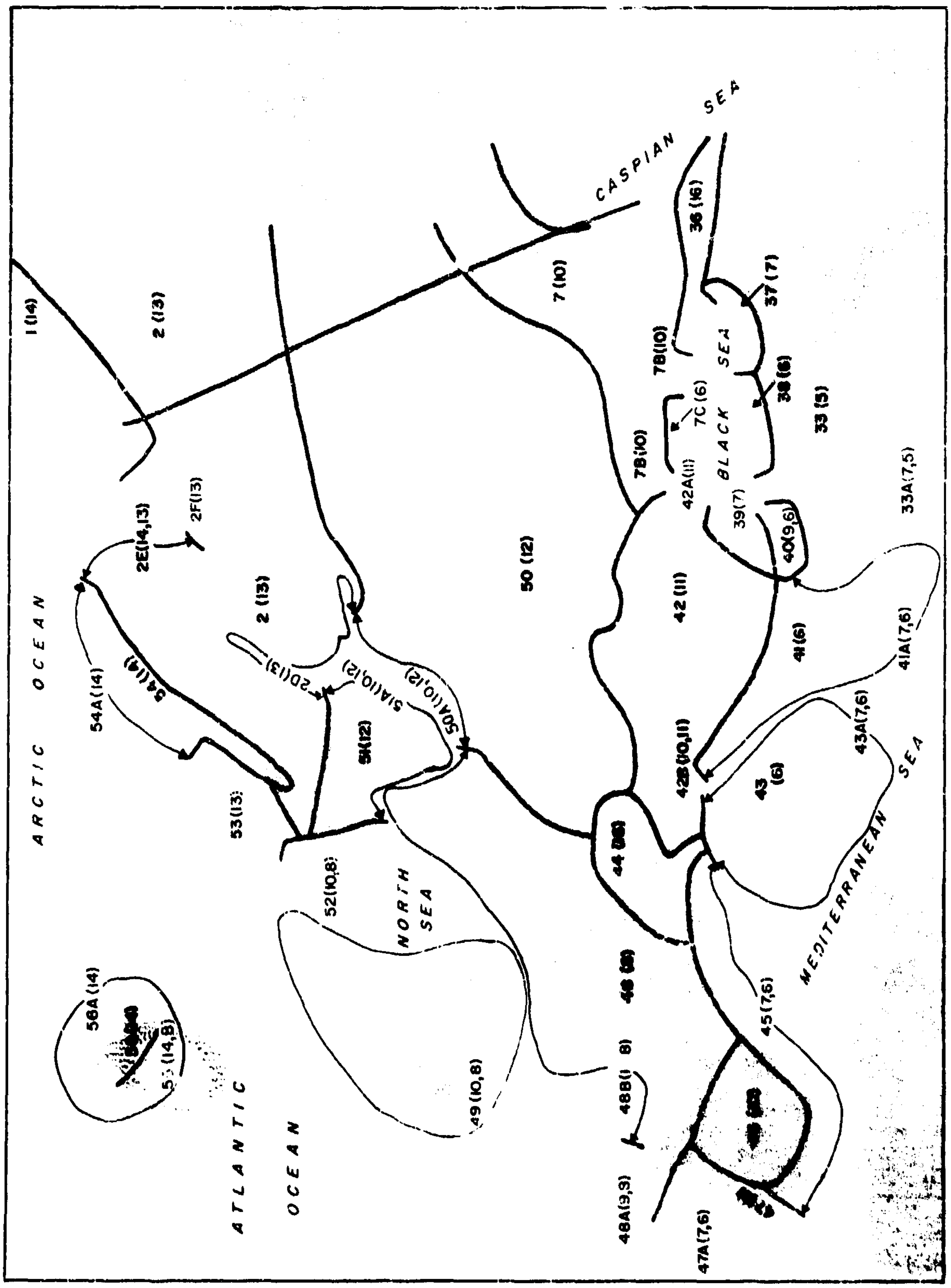


FIGURE 2
Climatic Zones of Asia

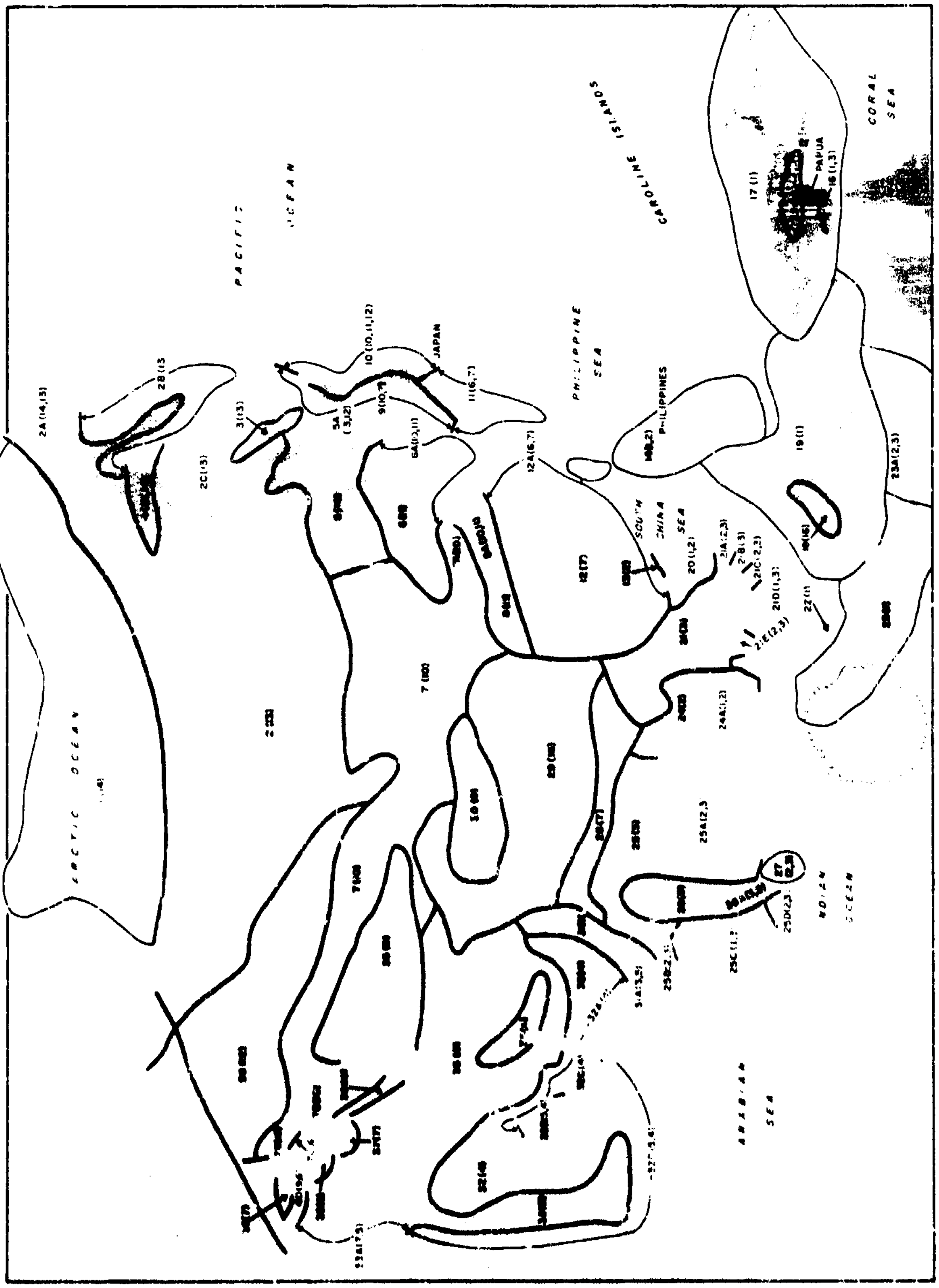


FIGURE 3
Climatic Zones of Africa

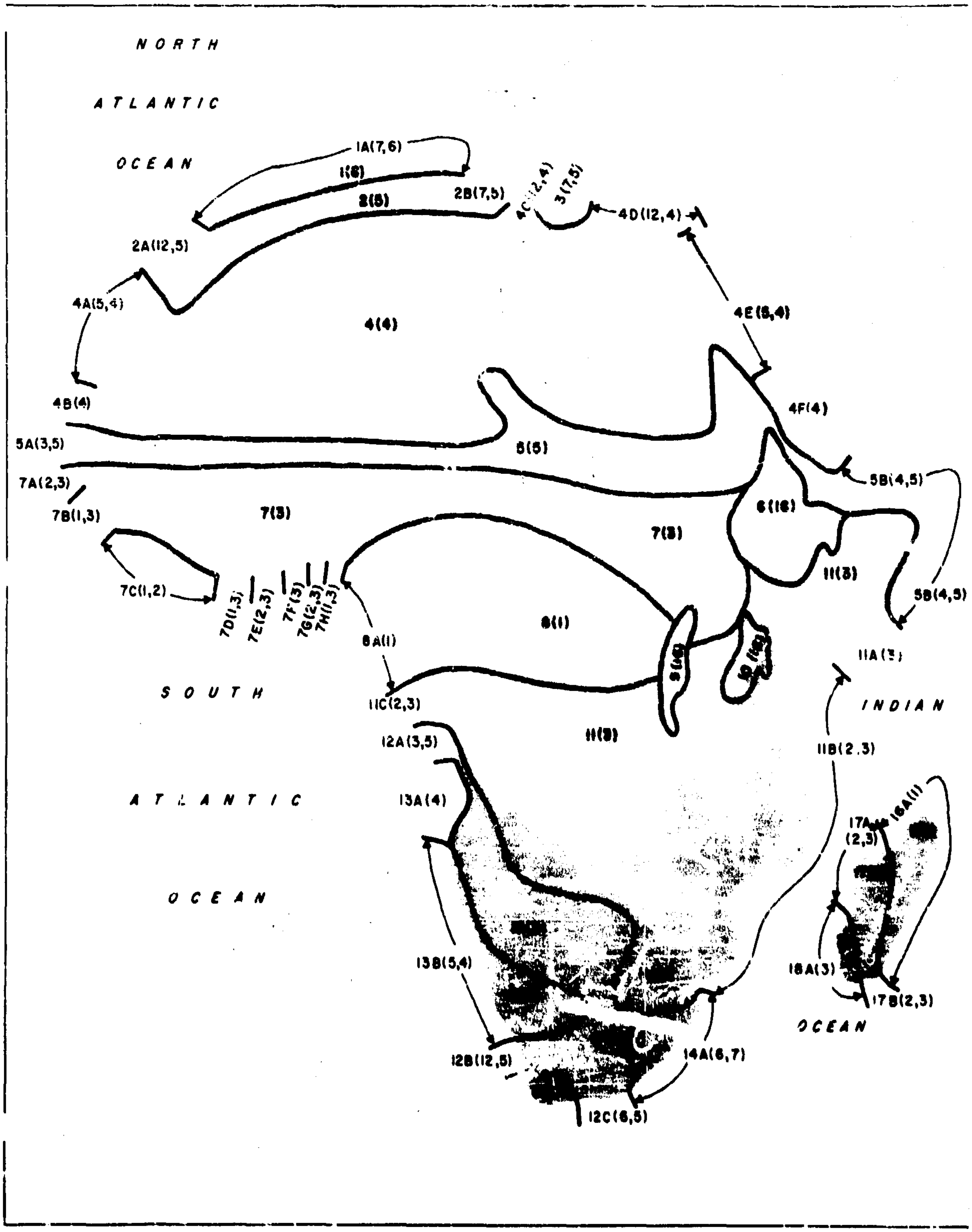


FIGURE 4
Climatic Zones of South America

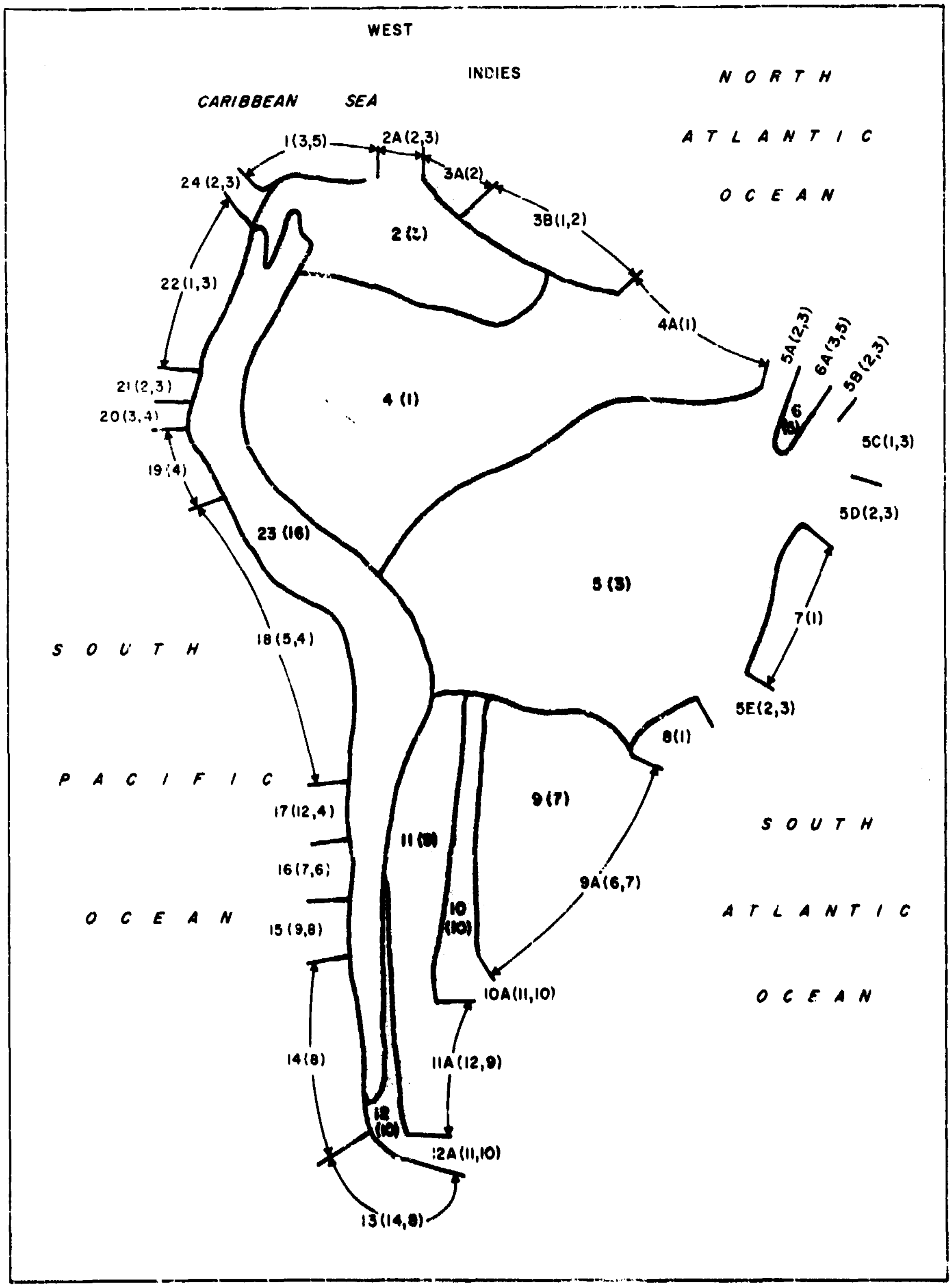


FIGURE 5
Climatic Zones of North America

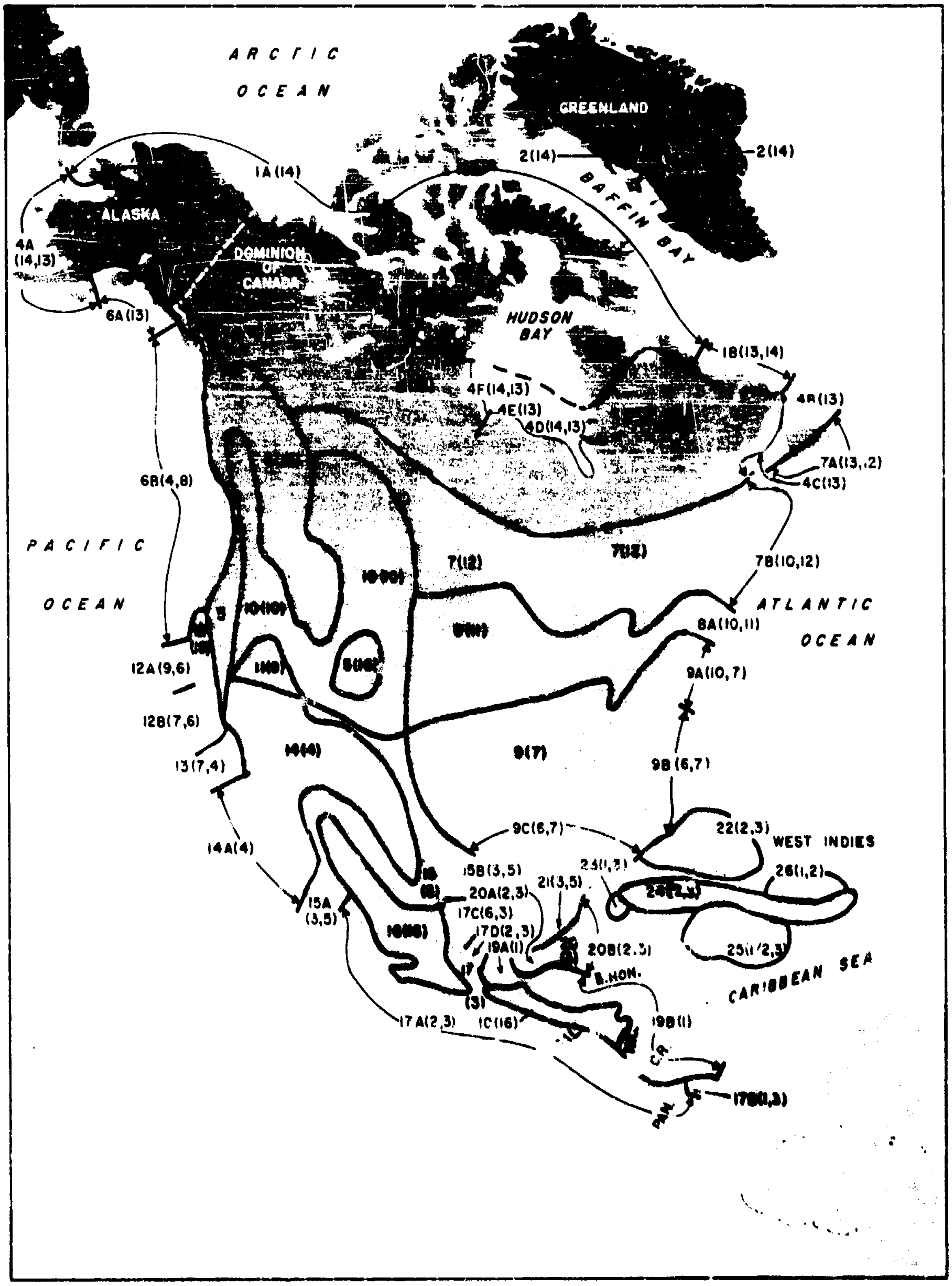


FIGURE 6
Climatic Zones of Oceania

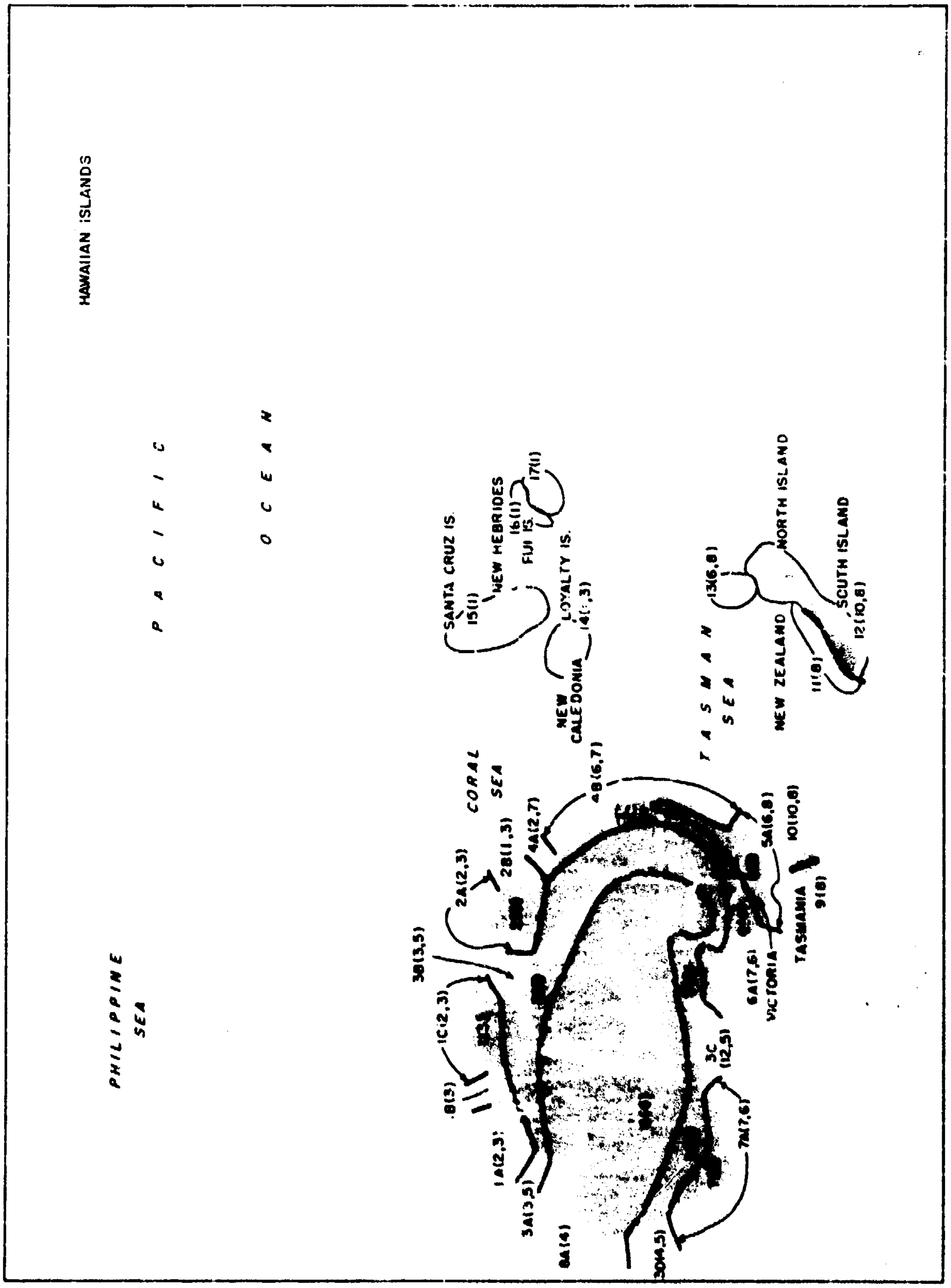
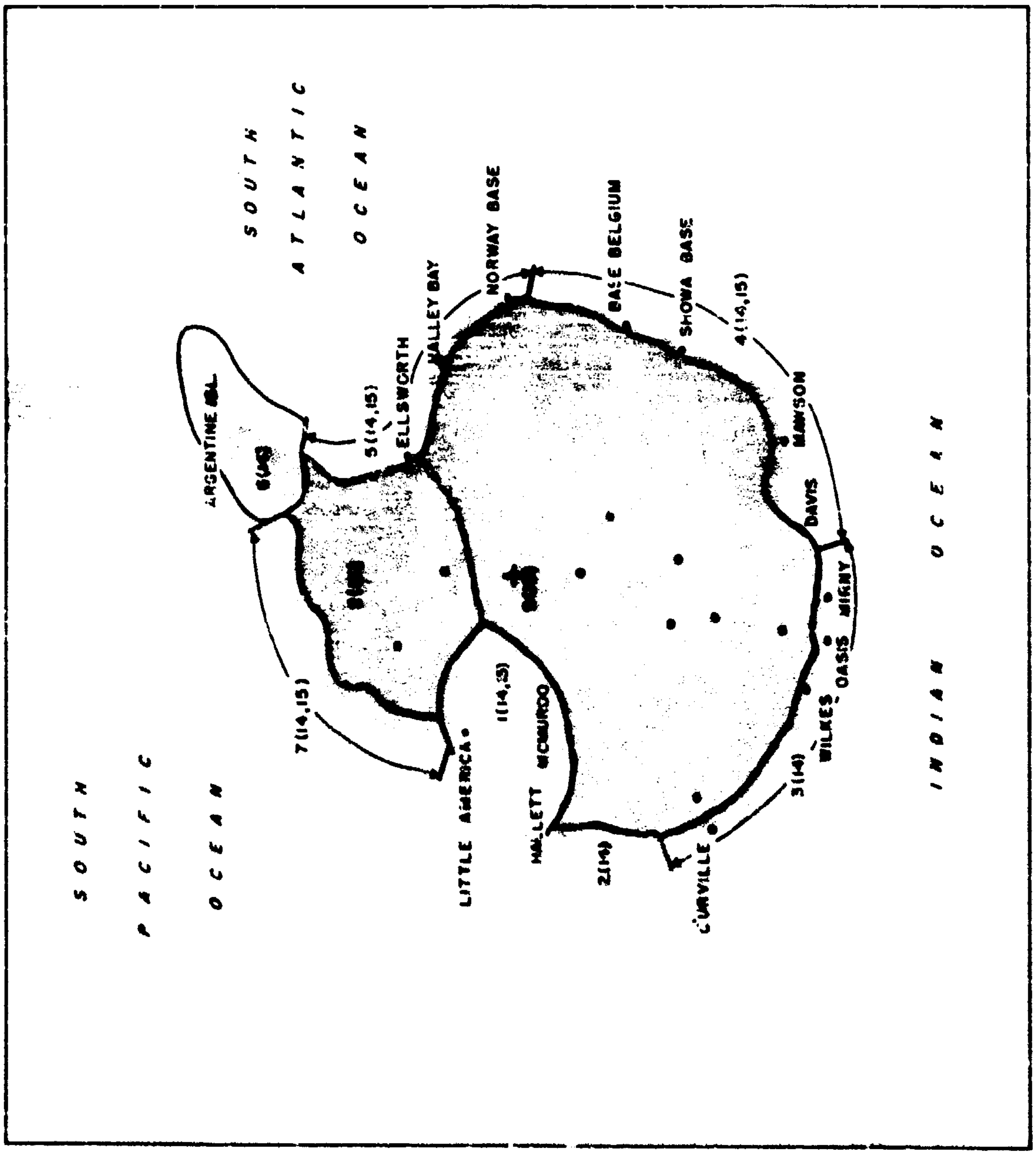


FIGURE 7
Climatic Zones of Antarctica



listing of climatic classifications is given in Table 2 and his boundaries are indicated in Figures 1 to 7. It will be noted in these figures and in Tables A-1 to A-6 in Appendix A that the agreement between the Bailey and Critchfield classifications and boundaries in the vicinity of the coasts is remarkably good.

The general climatic characteristics specified by both Bailey and Critchfield, and the statistics given by Bailey in Tables 1 and 2 are mean values determined on a world-wide basis. However, the parameter values for individual zones may or may not correspond well with these world-wide averages. For this reason, observed rather than world-wide average values for each zone are listed with the other pertinent parameters in the tables in Appendix A. A discussion of the details of acquisition of the data is also given in Appendix A.

Of the many attempts to divide the oceans into climatic zones, none has been successful. Although areas two to five degrees on a side are frequently used as the basis for analysis of climatic data, such arbitrary designation of boundaries is meaningless in the climatic zone sense unless the zones are so small as to make their numbers unmanageable. Consequently it has been found

Table 2
Critchfield's Climatic Classifications*

I.	Climates dominated by equatorial and tropical air masses
	1. Rainy tropics
	2. Monsoon tropics
	3. Wet-and-dry tropics
	4. Tropical arid climate
	5. Tropical semi-arid climate
II.	Climates dominated by tropical and polar air masses
	6. Dry summer subtropics
	7. Humid subtropics
	8. Marine climate
	9. Mid-latitude arid climate
	10. Mid-latitude semi-arid climate
	11. Humid continental warm summer climate
	12. Humid continental cool summer climate
III.	Climates dominated by polar and arctic-type air masses
	13. Taiga
	14. Tundra
	15. Polar climate
IV.	Climates having altitude as the dominant control
	16. Highland climates

* Reference 4, p. 174.

most practical to consider each ocean as a whole and examine the distribution of climatic features over the ocean.

The only known comprehensive presentation of climate over the oceans is that contained in the <u>Marine Climatic Atlas of the World</u> (15-19) and related documents prepared by the U. S. Navy Hydrographic Office and U. S. Weather Bureau. (14, 22) Because these documents are available to readers of this report, and because of the nature and volume of this material, no attempt is made to reproduce it here. The essential features for a winter month and a summer month are summarized in the subsection "Climatic Features of World Ocean Areas."

The ultimate sources of all climatic data used in this study are the observations of weather made at thousands of stations and transmitted over regional and world-wide communications networks. These observations have been processed into climatological summaries and tables, either by the weather services of the individual countries or by our own weather agencies. The characteristic values tabulated in Appendix A are based mostly on tabulations of climatic data prepared by the Climatological Section of the Air Weather Service, U. S. Air Force, by the Naval Weather Service

and Hydrographic Office and by the U. S. Weather Bureau. The process by which the characteristic values within each zone were obtained is also explained in Appendix A.

(2) Climatic Features Of World Land Areas

Critchfield (4, page 3) defines climate as "the aggregate of atmospheric conditions over a long period of time." Climate is a function of both average conditions and extremes. It is a function of the range and temporal distribution of temperature, rainfall, humidity, wind, cloudiness, and many other factors. Climate classification must, therefore, be based on all of these factors; however, temperature, precipitation, and wind speed are considered to be the most important.

In his efforts to devise a climatic indicator, man has been unable to improve upon the vegetation cover. Vegetation in a zone truly reflects the totality of the climatic influences and is therefore the most useful indicator of climatic type. This fact has been utilized in the development of all classification systems currently in vogue.

The boundaries and classifications of the climatic zones used in this study are shown on Figures 1 t. [illegible]. In these figures, arbitrarily assigned zone numbers are

keyed to the numbers that appear in column 1 of Tables A-1 to A-6 in Appendix A. The climatic classification for each zone appears in parentheses immediately following the zone number and in columns 2 and 3 of the tables in Appendix A. Where both the Bailey and Critchfield classifications apply, and they differ, the first given (in the figures) is Bailey's and the second is Critchfield's. The climatic characteristics for each classification are given in Tables 1 and 2 and are discussed in Appendix A.

Table 3 summarizes the distribution of Bailey's climatic classifications by country, continent, and the world. A similar summarization for the Critchfield classification is presented in Table 4.

From a study of these tables and figures, a picture of the world-wide distribution of climatic zones emerges. The most common coastal classification is polar, with 25 per cent of the world's coastlines. By adding the sub-polar classification, the total becomes 31 per cent. The polar zones extend along the northern rim of North America, Europe and Asia, around the Antarctic continent, and include the tip of South America. Characteristic features are temperatures mostly near or below the freezing level, persistent snow cover, sea-ice in the adjacent ocean areas, and, in the northern hemisphere, the prevalence of fog during a large portion of the year. A corresponding area in Critchfield's classification, that

TABLE 3

DISTRIBUTION OF COASTAL CLIMATES WITHIN POLITICAL BOUNDARIES

Continent	Political Unit	Per Cent of Coastline Within Bailey's Climatic Class No.													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Asia		34	10	1	4	6	7	2			11			11	14
	Aden					100									
	Borneo (Indo)	100													
	Burma	100													
	Cambodia	100													
	Ceylon		100												
	China	5	5				35				35				
	Cyprus							100							
	Formosa						100								
	India	25	50	23	2										
	Indonesia	98	2												
	Iran				100										
	Iraq				100										
	Israel							100							
	Japan						30				70				
	Korea (No)										100				
	Korea (So)										100				
	Kuwait				100										
	Lebanon							100							
	Malaya	100													
	New Guinea (Br)	100													
	New Guinea (Neth)	100													
	Oman				50	50									
	Pakistan - East	40	60												
	Pakistan - West				100										
	Philippines	100													
	Sarawak	100													
	Saudi Arabia				10	90									
	Siberia										1			54	45

TABLE 3 (Cont.)

DISTRIBUTION OF COASTAL CLIMATES WITHIN POLITICAL BOUNDARIES

Continent	Political Unit	Per Cent of Coastline Within Bailey's Climatic Class No.													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Asia (continued)	Solomon Is. (Br)	100													
	Syria							100							
	Thailand	80	20												
	Turkey (Asiatic)							90		10					
	Viet Nam (No)	50					50								
	Viet Nam (So)	65	25	10											
	Yemen					100									
Europe								37		1	35			11	16
	Albania							100							
	Belgium										100				
	Corsica							100							
	Crete							100							
	Denmark										100				
	England										100				
	Estonia										50			50	
	Finland													100	
	France							25			75				
	Greece							98		2					
	Germany East										100				
	Germany West										100				
	Iceland														100
	Ireland										100				
	Ireland (No)										100				
	Italy							90			10				
	Latvia										100				
	Lithuania										100				
	Netherlands										100				
	Norway										30			25	45

TABLE 3 (Cont.)

DISTRIBUTION OF COASTAL CLIMATES WITHIN POLITICAL BOUNDARIES

Continent	Political Unit	Per Cent of Coastline Within Bailey's Climatic Class No. 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Europe (continued)	Poland										100				
	Portugal							100							
	Sardinia							100							
	Scotland										100				
	Sicily							100							
	Spain							65		15	20				
	Sweden										65			35	
	Turkey (European)									100					
	USSR (European)													30	70
	Yugoslavia							75			25				
Africa		19	17	7	17	1[illegible]	7	13					9		
	Algeria							100							
	Angola			25	55	20									
	Cameroun	100													
	Congo Rep. (Br)		100												
	Congo Rep. (Fr)		100												
	Dahomey		100												
	Egypt					50							50		
	Eritrea				100										
	Gabon	70	30												
	Gambia		100												
	Ghana	10	50	40											
	Guinea	100													
	Guinea (Port)	60	40												
	Ivory Coast	100													
	Kenya		100												
	Liberia	100													

TABLE 3 (Cont.)

DISTRIBUTION OF COASTAL CLIMATES WITHIN POLITICAL BOUNDARIES

Continent	Political Unit	Per Cent of Coastline Within Bailey's Climatic Class No. 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Africa (continued)	Libya							50					50		
	Malagasy Rep	55	25	20											
	Mauritania				60	40									
	Morocco							65					35		
	Mozambique		100												
	Nigeria	100													
	Rio Muni	100													
	Senegal		15	85											
	Sierra Leone	100													
	Somalia			25	75										
	Somaliland (Br)				100										
	Somaliland (Fr)				100										
	South Africa					5	60	20					15		
	Southwest Africa					100									
	Spanish Sahara					90							10		
	Sudan				50	50									
	Tanganyika		100												
	Togoland		100												
	Tunisia							100							
South America		28	10	9	4	10	10	1	6	1		4	8		9
	Argentina						25					25	40		10
	Brazil	60	20	5			15								
	Chile					15		5	40	5			5		30
	Colombia	60	15	25											
	Ecuador	55	45												
	Guiana (Br)	100													
	Guiana (Fr)	100													
	Peru			10	30	60									

TABLE 3 (Cont.)

DISTRIBUTION OF COASTAL CLIMATES WITHIN POLITICAL BOUNDARIES

Continent	Political Unit	1	2	3	4	5	6	7	8	9	10	11	12	13	14
		Per Cent of Coastline Within Bailey's Climatic Class No.													
South America (continued)	Surinam	100													
	Uruguay						100								
	Venezuela	5	50	45											
North America		6	12	2	5		5	2		7	4			10	47
	Alaska									15				15	70
	Bahamas		100												
	British Honduras	100													
	Canada									5	5			15	75
	Costa Rica	30	70												
	Cuba	25	75												
	Dominican Rep.	35	65												
	Greenland														100
	Guatemala	25	75												
	Haiti	50	50												
	Honduras	100													
	Jamaica		100												
	Mexico	3	35	15	40		5	2							
	Nicaragua	60	40												
	Panama	45	55												
	Puerto Rico		100												
	Salvador		100												
	USA		2	2			45	10		21	20				

TABLE 3 (Cont.)

DISTRIBUTION OF COASTAL CLIMATES WITHIN POLITICAL BOUNDARIES

Continent	Political Unit	Per Cent of Coastline Within Bailey's Climatic Class No. 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Southwest Pacific		10	16	6	7		20	17	8		15		1		
	Australia	5	30	10	10		20	20					5		
	Fiji	100													
	New Caledonia	100													
	New Hebrides	100													
	New Zealand						15		25		60				
	Tasmania								50		50				
Antarctica															100
WORLD		20	10	2	5	4	6	7	1	2	9	1	3	6	25

TABLE 4

DISTRIBUTION OF CRITCHFIELD'S CLIMATIC ZONES WITHIN POLITICAL BOUNDARIES

Continent	Political Unit	Approximate Area (Sq. Mi.)	Per cent of Area Within Class No. (See Table 2)															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Asia		17,388,748	6	1	7	6	13	*	8	0	6	11	3	6	19	4	0	10
	Aden	112,108				70	30											
	Afghanistan	250,965				10	80											10
	Bhutan	19,305							50									50
	Borneo (Indo.)	208,285	90															10
	Burma	261,757		45	40				15									
	Cambodia	69,884			100													
	Ceylon	25,332		25	75													
	China	3,827,911			5				30		10	20	10	10				15
	Cyprus	3,572					100											
	Formosa	13,886							100									
	India	1,065,703			45	2	33		15									5
	Indonesia	367,608	97		3													
	Iran	636,293				20	80											
	Iraq	171,580				35	65											
	Israel	7,984					100											
	Japan	142,801							50				25	25				
	Jordan	37,313					100											
	Kashmir	92,780																100
	Korea (No.)	49,114											100					
	Korea (So.)	37,401											100					
	Kuwait	8,000				100												
	Laos	91,500			100													
	Lebanon	4,015					100											
	Malaya	50,980	100															
	Mongolia	614,350										95		2	3			
	Nepal	54,610							50									50
	New Guinea (Br.)	183,540	60		10													30
	New Guinea (Neth.)	180,618	80		10													10

* <0.5%

TABLE 4 (Cont.)

DISTRIBUTION OF CRITCHFIELD'S CLIMATIC ZONES WITHIN POLITICAL BOUNDARIES

Continent	Political Unit	Approximate Area (Sq. Mi.)	Per cent of Area Within Class No. (See Table 2)															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Asia (Cont'd.)	North Borneo	29,388	100															
	Oman	114,300				100												
	Pakistan (East)	54,501		25	50				25									
	Pakistan (West)	310,236				50	40											10
	Philippines	115,707	75	25														
	Sarawak	47,071	35															65
	Saudi Arabia	625,760				65	35											
	Solomon Is. (Br.)	11,500	100															
	Syria	71,227					100											
	Thailand	198,270	20	10	70													
	Tibet	469,413																100
	Timor (Port.)	7,332			100													
	Turkey (Asiatic)	292,550					85	10	5									
	USSR (Asiatic)	6,372,000					5				10	10		10	50	10		5
	Viet Nam (No.)	59,600		30					70									
	Viet Nam (So.)	66,000		25	75													
	Yemen	75,290				30	70											
Europe		3,818,336	0	0	0	0	0	7	*	14	*	10	8	36	18	4	0	3
	Albania	11,100						100										
	Austria	32,374											30	45				25
	Belgium	11,779								100								
	Bulgaria	42,818							25				75					
	Corsica	3,367						100										
	Crete	3,235						100										
	Czechoslovakia	49,366											25	75				
	Denmark	16,577								100								

* < 0.5%

TABLE 4 (Cont.)

DISTRIBUTION OF CRITCHFIELD'S CLIMATIC ZONES WITHIN POLITICAL BOUNDARIES

Continent	Political Unit	Approximate Area (Sq. Mi.)	Per cent of Area Within Class No. (See Table 2)															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Europe (Cont'd)	England	50,871								100								
	Estonia	17,413												85	15			
	Finland	130,119													98	2		
	France	209,369						5		85								10
	Germany (East)	41,633								45				55				
	Germany (West)	95,896								80				20				
	Greece	47,947						98	2									
	Hungary	35,906							2				98					
	Iceland	39,768								10						90		
	Ireland	27,136								100								
	Ireland (No.)	5,450								100								
	Italy	97,092						60					20					20
	Latvia	24,595												100				
	Lithuania	25,174												100				
	Luxembourg	999								100								
	Netherlands	12,482								100								
	Norway	125,064								15				30	20	45		
	Poland	120,356											1	99				
	Portugal	35,520						100										
	Romania	91,390							2				98					
	Sardinia	9,301						100										
	Scotland	29,795								100								
	Sicily	9,926						100										
	Spain	194,945						20		35		45						
	Sweden	173,364												40	50	10		
	Switzerland	15,941																100
	Turkey (European)	10,500						70	30									
	USSR (European)	1,881,000									1	15	1	53	25	3		2

* <0.5%

TABLE 4 (Cont.)

DISTRIBUTION OF CRITCHFIELD'S CLIMATIC ZONES WITHIN POLITICAL BOUNDARIES

Continent	Political Unit	Approximate Area (Sq. Mi.)	Per cent of Area Within Class No. (See Table 2)															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Europe (Cont'd)	Wales	7,474								100								
	Yugoslavia	98,766						20					80					
Africa		11,[illegible]27,601	10	1	36	29	18	2	1									3
	Algeria	919,560				75	15	10										
	Angola	493,351			75	2	23											
	Cameroun	166,793	85		15													
	Cen. African Rep.	238,224	65		35													
	Chad	495,792	2		28	25	45											
	Congo Rep. (B.)	904,981	50		50													
	Congo Rep. (Fr.)	132,046	60		40													
	Dahomey	43,764			100													
	Egypt	386,100				100												
	Eritrea	45,946				50	50											
	Ethiopia	409,266			20													70
	Gabon	103,089	80		20													
	Gambia	4,003			100													
	Ghana	91,843			100													
	Guinea	106,216			100													
	Guinea (Port.)	13,948			100													
	Ivory Coast	123,282		10	90													
	Kenya	223,478			80													20
	Liberia	43,000		85	15													
	Libya	679,358				98	2											
	Malagasy Rep.	227,737	50		50													
	Mali	463,948			15	60	25											
	Mauritania	418,961				95	5											
	Morocco	174,418					70	30										

TABLE 4 (Cont.)

DISTRIBUTION OF CRITCHFIELD'S CLIMATIC ZONES WITHIN POLITICAL BOUNDARIES

Continent	Political Unit	Approximate Area (Sq. Mi.)	Per cent of Area Within Class No. (See Table 2)															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Africa (Cont'd)	Mozambique	297,846			100													
	Niger	484,633			5	70	25											
	Nigeria	373,250	30		70													
	Nyasaland	49,177			100													
	Rhodesia (No.)	290,323			100													
	Rhodesia (So.)	150,333			100													
	Rio Muni	10,831	100															
	Ruanda-Urundi	20,916																100
	Senegal	80,617			30	10	60											
	Sierra Leone	27,925		50	50													
	Somalia	178,201			60		40											
	Somaliland (Br.)	67,997			50		50											
	Somaliland (Fr.)	8,108					100											
	South Africa	765,296			15		70	5	10									
	Southwest Africa	317,887			10	40	50											
	Spanish Sahara	102,703				70	30											
	Sudan	967,490			35	20	35											
	Tanganyika	362,708			90													10
	Togoland	21,236			100													
	Tunisia	48,332				20	45	35										
	Uganda	93,981			80													20
	Voltaic Rep.	106,046			80		20											
South America		6,874,373	24	1	40	1	1	*	8	2	8	4						11
	Argentina	1,084,360							24	1	50	25						
	Bolivia	424,162	15		55													30
	Brazil	3,287,195	34		60		1		5									
	Chile	286,396				10		5		40								45

* < 0.5%

TABLE 4 (Cont.)

DISTRIBUTION OF CRITCHFIELD'S CLIMATIC ZONES WITHIN POLITICAL BOUNDARIES

Continent	Political Unit	Approximate Area (Sq. Mi.)	Per cent of Area Within Class No. (See Table 2)															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
South America (Cont'd.)	Colombia	439,519	50	5	15													30
	Ecuador	104,684	15		25													60
	Guiana (Br.)	83,000		25	75													
	Guiana (Fr.)	35,135	35	35														
	Paraguay	157,047			50				45		1	4						
	Peru	496,222	25			10												55
	Surinam	56,143	40	40	20													
	Uruguay	68,359							100									
	Venezuela	352,142	5	5	85		5											
North America		9,349,708	1	*	3	5	2	1	6	1	1	7	6	10	25	11	7	11
	Alaska	586,400									5				65	15		15
	Bahamas	4,404			100													
	British Honduras	8,867	100															
	Canada	3,845,774								1		5		15	50	20		9
	Costa Rica	19,695	25		75													
	Cuba	44,218			100													
	Dominican Rep.	18,703	50	50														
	El Salvador	8,260			100													
	Greenland	840,000														25	75	
	Guatemala	42,042	30		35													35
	Haiti	10,714			100													
	Honduras	43,277	40															60
	Jamaica	4,700			100													
	Mexico	760,373	5		20	25	20											30
	Nicaragua	57,143	50		30													20
	Panama	29,306	50		50													

* < 0.5%

TABLE 4 (Cont.)

DISTRIBUTION OF CRITCHFIELD'S CLIMATIC ZONES WITHIN POLITICAL BOUNDARIES

Continent	Political Unit	Approximate Area (Sq. Mi.)	Per cent of Area Within Class No. (See Table 2)															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
North America (Cont'd.)	Puerto Rico	3,435		50	50													
	USA	3,022,587			1	10	3	2	25	2	2	15	20	10				10
Southwest Pacific		3,103,411	1		10	44	28	5	5	7								
	Australia	2,948,366			10	47	30	5	5	3								
	Fiji	7,057	100															
	New Caledonia	6,533	100															
	New Hebrides	11,500	100															
	New Zealand	103,740								100								
	Tasmania	26,215								100								
Antarctica		5,500,000														5	95	
WORLD		[illegible],760,1[illegible]	7	1	15	11	10	1	5	2	3	6	2	6	10	4	10	*

* < 0.5%

dominated by polar or arctic-type air masses, similarly covers the largest single area of the continents, i.e., about 25 per cent.

The second longest coastline climatic type is rainy tropical with 20 per cent. Inclusion of the sub-humid tropical, i.e., monsoon type tropics, raises this figure to 30 per cent. These tropical coast-lines are found mainly in southeast Asia, Indonesia, India, the west coast of equatorial Africa, and the east coast of South America. Smaller sections are located in Central America and portions of Mexico and Colombia. The corresponding Critchfield climatic type covers a somewhat lower proportion of the land area than of the coastline, i.e., 7 per cent. If one includes, as before, the monsoon tropics and the wet-and-dry tropics, this figure increases to 23 per cent.

The characteristics of the true rainy tropical area are dense jungle up to the water's edge, a profusion of animal life of all types and sizes, frequent moderate to heavy rains, relatively low wind speeds, and an oppressively hot and humid condition. In the monsoon or tropical wet and dry climatic areas, the jungle sometimes gives way to grassland, and the rainy, humid seasons alternate with even warmer and/or drier seasons.

A third most important segment of the earth's surface is the arid or semi-arid group of zones. Approximately 30 per cent of the land surface and 14 per cent of the coastline falls in these classifications. About one-third of the earth's arid regions are found in Africa, mostly in the northern half. The remainder occur in southwestern and central Asia, southwestern North America, central and western Australia, and in southern and western South America. Vegetation in these regions is sparse or non-existent, the soil tends to be sandy or rocky, and the precipitation is seasonal. These are the areas in which most of the world's sand and dust storms occur.

The remainder of the earth's surface, approximately one-fourth of the coastline and 23 per cent of the surface, is distributed among the various temperate zones, most of which are characterized by wet-and-dry seasons and receive moderate amounts of precipitation. Vegetation in these zones consists primarily of forest and/or grasses.

1. Europe - Asia

The climate of the Eurasian continent, including the peripheral island ... ranges from the extreme cold and dryness of the Arctic coast and

northern Siberia to the extreme heat of the hyper-arid Arabian Peninsula and the extreme dampness of the jungles of Malaya and New Guinea. Mean temperatures increase in the usual manner from north to south. Mean temperatures also increase slightly from east to west, except over southeast China, because of the warming effect produced over western Europe by the Gulf Stream and because of the widespread radiational cooling that occurs over the great north Asian and northeast European land mass. Freezing temperatures and ground snow cover are common winter phenomena north of a line extending from Shanghai through northern India, Iran, and Turkey to southern France and thence north-northwest past northern Great Britain. These phenomena are relatively infrequent or non-existent to the south of this zone. The distribution of snow cover is illustrated in Figure 8, following page 85, which shows the approximate world-wide locations of given climatic features during the coldest winter months of each hemisphere.

The regions of heaviest precipitation are found, at least part of the year, in the monsoon belts of India and southeast Asia, in the vicinity of the intertropical convergence zone in Indonesia

and New Guinea, and on the southwest edge of the Pacific high pressure belt in the Philippines. Little rain is found in the "rain shadow" of the mountain ranges such as those in southwest and central Asia. Precipitation is also slight in Arabia at the east end of the unique Mediterranean east-west oriented dry belt. Western Europe, which is dominated by the subpolar belt of westerly wind, has a rainy marine climate. Rainy subtropical and temperate wet-and-dry climates, characteristic of the western side of oceanic high pressure cells, are found in eastern China and Japan.

Relative humidities conform generally to the descriptive terms of the climatic classifications. They are very high in the tropical rainy climates, high in the rainy seasons elsewhere, low in dry seasons and very low in arid regions, particularly in portions of the Arabian Peninsula.

Thunderstorms occur mostly in the tropical maritime air masses over India, southeast Asia, Indonesia, and the Philippines. In some locations in these areas, thunderstorms are almost a daily occurrence during a large portion of the year. As a general rule, they tend to o... a short distance

inland, away from the beaches. The highlands of New Guinea and Borneo are favored locations for such storms.

Data on the occurrence of sand and dust storms are extremely sparse. The storms are known to occur almost entirely in arid regions such as the Arabian Peninsula and the desert portions of Iran, Afghanistan, northwestern China, Mongolia, and Manchuria. In these areas the soil is sandy or lacking in plants or other binding materials. The most frequent reported occurrences are 135 days per year on the east and south coasts of Saudi Arabia, 183 days per year at a place in the Sinkiang province of China, and 110 days per year at a point in the Gobi Desert of Mongolia. In such places, the high frequency of sandstorms is probably favored by combinations of terrain and prevailing winds which must also occur in many other localities in the arid regions. Elsewhere in these same regions frequency of occurrence is probably much less; however, soil conditions are favorable for the creation of local duststorms by propwash from airplanes or downwash from GEMs.

Very little of a special nature can be said about wind speed and direction over any considerable area. Both speed and direction are strongly influenced by terrain and surface conditions so that wide variability within even small regions is not uncommon. Wind speeds tend to be strongest in the storm belts of the middle and high latitudes, especially along the coasts in the winter. In the summer they tend to be stronger during certain hours of the afternoon or early morning in valleys or canyons or along the drier coasts, especially when the gradient is directed parallel to these features. Speeds are generally low in the lower latitudes, except in the vicinity of thunderstorms. Table A-1 of Appendix A indicates specific regions in which stronger winds tend to occur.

The occurrence of fog along the coast is largely seasonal. It occurs quite commonly along the Arctic coast from northern Europe eastward to the Pacific, along the Pacific coast to Japan and Korea, and along the south China coast. Those zones in which fog occurs with the frequency specified by Bailey in his criteria are indicated in Table A-1, Appendix A. (Bailey's fog criteria include occurrence of dense fog (limiting visibility to 1100

yards or less) either 20 per cent of the time in a month, or 15 per cent in a three-month period, or 10 per cent in a year.) No attempt was made to classify continental zones according to the occurrence of fog since fog in these areas is normally limited to interior valleys in the early morning hours and is usually not of area-wide significance.

2. Africa

Largely because of its position astride the equator, Africa encompasses the narrowest range of temperature regimes and the widest range of rainfall regimes of any of the continents. The most striking feature of the continent is the arid Sahara Desert in which daytime temperatures over 120° F. and relative humidities under 20 per cent are common.

The average of the mean temperatures over the entire continent of Africa is undoubtedly the highest of any of the continents. Mean daily minimum temperatures below freezing during the coldest month occur only along the northern rim and southern tip of the continent and at a few places in the Sahara and in the higher mountains.

Mean daily maximum temperatures during the warmest month over most of the continent range between 85° F. and 98° F., but are as high as 117° F. in the Sahara. In the tropical humid zones, temperatures generally range over the year between 60° F. and 90° F., seldom exceeding 100° F. or dropping below 50° F.

The northern 1/3 to 2/5 of Africa constitutes the largest single arid region on earth. It is the only region found for which some climatic stations report an average annual rainfall of zero. Many average only a trace and most average less than one inch per year. The other smalle arid regions, found in southwest Africa at the east end of the south Atlantic high-pressure belt and on the eastern tip of the continent in the rain shadow of the Ethiopian mountain range, also receive very small quantities of rain. In contrast the Congo Basin, which is dominated by the intertropical convergence zone, receives copious quantities. As a rule, the rainfall in Africa is greater in coastal areas than in the interior, especially in the more temperate climates found at the northern and southern ends of the continent.

Relative humidities are high in the Congo Basin and along the central west coast, and they are very low in the Sahara and along the east and the southwest coasts. They vary seasonally in the usual manner as elsewhere, according to wet or dry season.

Frequency of occurrence of thunderstorms is very high in the vicinity of the intertropical convergence zone, especially in the Congo where they occur as much as 200 days per year. Thunderstorm activity is also very frequent on Madagascar and on the southeast coast in the tropical maritime air flowing around the west end of the Indian Ocean high pressure belt. Elsewhere in Africa, thunderstorms vary in frequency from about 25 days per year along the Mediterranean coast to less than one day per year along the Red Sea coast. Thunderstorms occur more frequently a few miles inland than on the immediate coastline.

Although the maximum reported frequency of occurrence of sand and dust storms in the Sahara is approximately 60 days per year, it is probable that they are more prevalent in some areas not covered by weather observations. The sandstorm maximum generally occurs in the period from January through April when wind speeds above 15 to 25 knots are more prevalent.

As is the case with most land areas, only general statements can be made about wind direction and speed. Sea and land breezes, sometimes quite strong, occur along most of the coast of Africa. In addition, there are many local winds, such as the Sirocco, which are capable of raising dust and sand. On the whole, the strongest winds are found on the fringe of the temperate or subpolar storm belt at the tip of South Africa. An exception to this is along the Coast of Somalia, on the eastern tip of Africa, where gale-force winds and accompanying sandstorms are most frequently reported. Except in the immediate vicinity of some thunderstorms, wind speeds in the jungle area of central Africa are relatively light.

Fog meeting Bailey's frequency criteria occurs primarily along the coast of southwest Africa on the east end of the south Atlantic subtropical high-pressure belt. Fog also occurs during night and early morning hours in many mountain valleys and some river valleys of south and east Africa; however, frequency of occurrence does not warrant classification of any zones as fog zones.

3. South America

Although the bulk of South America lies within the tropics, its southern tip extends well into the prevailing westerlies of the subpolar storm belt. Thus its climates range from the dominant rainy tropical and wet-and-dry tropics of the north to the polar climate at the southern tip.

The controlling factor in South America's climates is the Andes Mountain Range that extends down almost the entire length of the west side of the continent. This range restricts the effect of the intertropical convergence zone on the west coast to the region from the equator northward. To the south the coast is dominated by the east end of the South Pacific high-pressure belt and the typical arid climate associated with its subsiding flow. The Andes also act as the western barrier to the flow of the tropical air around the south Atlantic high-pressure belt. This flow of moist, tropical air, plus the action of the intertropical convergence zone, produces the dominant [illegible] tropical climates of Brazil and the countries to the north.

Argentina and Chile extend from the subtropics, where they are influenced by the great high-pressure

belts of the two oceans, well into the prevailing westerlies that ring the globe north of the subpolar low-pressure belt. The climate in Chile thus ranges from arid on the north to rainy marine and very windy in the south. Because the Andes are very high through this belt, a rain shadow is found on their east side. Thus the climate of a large portion of Argentina is arid or semi-arid.

The extreme mean daily maximum temperatures so common in the Sahara in Africa are not found in South America. Highest temperatures occur in the arid subtropical regions of Argentina where some mean daily maxima of 100° F. or greater are found. Maximum temperatures in the tropical arid regions of northern Chile and Peru are limited to less than 90° F. by the low clouds and fog which, along with the lack of rainfall, characterize the eastern edges of high-pressure belts along the west coasts of continents. Maximum temperatures in the tropical belt east of the Andes usually remain in the nineties because of the effects of precipitation and cloudiness.

As can be seen in Figure 3, the extent of freezing temperatures and snow cover is relatively small on this continent and is confined to the

southern-most areas and the higher levels in the mountains. Mean daily minimum temperatures near or below freezing, as well as individual daily temperatures in the same range, are found only in the mountains or in the southern quarter of the continent during the winter months and almost never in the summer months.

The heavy rains of South America occur east of the Andes in the general equatorial belt where the intertropical convergence zone and the southwest and northwest sections of the North Atlantic and South Atlantic high-pressure belts respectively are the dominating influences. Even in this zone rainfall is seasonal, following as it does the movement northward in the northern hemisphere summer, and southward in the southern hemisphere summer of the intertropical convergence zone. A temperate rainy belt, in which rainfall is plentiful throughout the year, exists along the southern portion of Chile where it extends into the belt of westerlies known as the "roaring 40's." Precipitation elsewhere on the continent is essentially seasonal and relatively light.

Relative humidities generally conform to the descriptions of climatic classifications in that

they are high to very high in the tropical rainy belts and in the rainy section of Chile noted above. They are occasionally high during rainy seasons elsewhere and are quite low in the arid regions the year around.

Thunderstorms have been reported on as many as 190 days per year in those equatorial regions dominated by the intertropical convergence zone. Most thunderstorm activity occurs in or near this zone and in the tropical air masses flowing into the Andes Mountains or into higher latitudes. Thunder storm frequency seldom exceeds 25 to 30 days per year in the higher latitudes and is essentially zero in the arid climates.

There are no quantitative data available on the occurrence of sand and dust storms in South America. There is some evidence that they occur occasionally in the arid regions of Argentina and along the coast of northern Chile and southern Peru. Such storms appear to be of minor consequence on the continent of South America.

Wind speed and direction are influenced very strongly be terrain on this continent as they are on others, and a wide variability exists over relatively small regions. Directions are generally easterly in the tropics on the Atlantic side of the

Andes and westerly in the southern half of the Pacific side. Wind speeds, as a general rule, are quite light and calms quite frequent in the tropical jungle areas and even along the coast of most of tropical South America. In contrast, wind speeds are generally strong along the southern tip, particularly along the south coastal region of Chile. In the belt known as the "roaring 40's," frequency of gale winds is sometimes as high as 22 per cent, and wind speeds of ten knots or below occur only a very small fraction of the time.

Fog occurs, according to Bailey's criteria, along the coast of Peru and northern Chile under the influence of the eastern edge of the subtropical high-pressure belt. It also occurs in connection with storm activity along the southern coast of Chile in the belt of the "roaring 40's." Fog occurs in some interior valleys during early morning hours; however, frequency is not sufficient to warrant classification of any continental zones as fog zones.

4. North America

The climate of North America, like that of Asia, ranges from the extreme cold and dryness of the Arctic coast and islands to the rainy tropics

of Central America and the arid subtropics of the Southwest. The percentages of coastline length and land area bearing polar and subpolar classifications are about 57 per cent and 43 per cent, even higher than in Asia. In contrast, the proportions of coastline and continent classified either as rainy tropical or tropical arid are relatively small. The rainy and wet-and-dry tropics are found in Central America, part of Mexico, and the Caribbean islands. The relatively small arid region is confined to the southwestern United States and northwestern Mexico, although semi-arid belts extend northward over the Great Salt Lake Plateau and the western great plains, which lie in the rain shadows of the Cascade-Sierra Range and the Rockies respectively.

The dominant feature responsible for the North American climatic distribution is the complex of mountain chains extending from the Aleutians through southern Alaska, western Canada and United States, and thence through Mexico and Central America to Colombia where it joins the Andes. As a consequence of this physical barrier, the coasts of California and northern Mexico experience the low incidence of precipitation and the low clouds

typical of the subsiding eastern edge of high-pressure belts along west coasts of continents. In higher latitudes these mountains also act as barriers to eastward movement of storms and result in a wet climate on the windward side. The rain shadow effects of the coastal ranges are pronounced in interior plateaus.

The mountain chains also restrict the influence of the western end of the Atlantic high-pressure belt to the eastern half of the continent where humid tropical and subtropical climates prevail in the south and wet-and-dry temperate climates are found further north.

Mean temperatures over North America in the winter are somewhat higher along the Atlantic coast than in the middle of the continent. They are substantially higher along the Pacific coast under the influence of the diffuse Japanese Current and of the semi-permanent low-pressure area in the Gulf of Alaska.

The area of extreme daily mean maximum temperatures in the summer is found in the arid regions of the Southwest. However, only a few places, such as Death Valley, have such extremes as do the Sahara

and Arabian areas of the Asian and African continents. Extreme low temperatures during winter months recorded in northern Canada and Alaska compare with those recorded in Siberia. These low temperatures are usually found in valleys and east of the Rocky Mountains over the tundra of the Canadian plains. The extreme southward extent of ground snow cover can be noted in Figure 8. To the south of the snow belt, freezing temperatures are comparatively rare or non-existent and snow cover occurs very infrequently. During the summer months, the line recedes to the extreme north edge of the continent.

The greatest precipitation amounts recorded in North America, up to 150 inches per year, fall along the east coast of Central America and the east coast of the Gulf of Alaska. Moderate quantities fall in south-eastern United States and eastern Mexico. Rainfall over most of the continent is seasonal in nature, although precipitation in the dry seasons may reach five inches per month in the Central American area contrasted to zero in the southwest arid regions. Precipitation is the least in southwestern United States and northwestern Mexico, where a large part of the region

is in the rain shadow of mountains and the coastal portions are influenced by their location at the eastern edge of the Pacific subtropical high-pressure belt. Showers and thunderstorms occur here in the infrequent incursions of Gulf air. The most nearly uniform precipitation distribution on the continent occurs along the Atlantic coast where rain or snow falls from 8 to 16 days per month throughout the year.

Very high values of mean relative humidity are found the year around only in the Central American area. Elsewhere, they occur intermittently, being high along the Pacific coast, California northward, only during the winter wet season, and in the southeast and eastern part of the country during the summer season. Very low relative humidities occur most of the year in the southwest arid regions, in parts of which they are almost as low as those found in the Sahara.

Maximum thunderstorm activity occurs in the flow of tropical air around the southwest side of the North Atlantic high-pressure belt, especially in the vicinity of the intertropical convergence zone in the Panama to Nicaragua area where they occur up to 100 days per year. Considerable

thunderstorm activity is found in the West Indies and the southern tip of Florida; and moderate activity extends throughout the plains states and the Atlantic coastal region of the United States during the summer months.

Elsewhere on the continent, thunderstorm activity is comparatively infrequent. One area of special note is just to the east of the Rocky Mountains in Kansas, eastern Colorado, eastern Wyoming and Oklahoma. In this area very strong thunderstorms with hail and tornadoes have a maximum frequency of occurrence in April, May, and June. Most of the thunderstorms observed on the continent accompany an incursion of tropical air from the Gulf of Mexico.

Blowing sand and dust on the North American continent are confined almost entirely to the arid regions of the southwest and are not a significant feature. In this region sand or dust storms may occur as much as 50 days per year, mostly in the early spring months. During periods of extended drought, such as those of the 1930's, blowing dust may also cover extensive areas of the western plains section. Critical wind speed required to raise the sand grains over the desert regions appears to be approximately 25 to 30 knots.

Although strongly influenced or dominated by terrain features, there are some well defined wind patterns apparent in the circulation over North America. Typical of these are the southeasterly and easterly flows along the Gulf and southeast coasts in the summertime, the westerly flow along the Pacific coast from northern Mexico to southern Alaska throughout the year, and the northerly flow over Canada and the United States in winter. Gale force winds in the warmer months are usually connected with special situations such as Atlantic hurricanes traveling up the east coast in the fall. In the winter, gale winds accompanying the major storms in the subpolar storm belt affect particularly the Pacific coast from California northward, the Atlantic coast northward from the Carolinas, and occasionally the Midwest northwestward through the Great Lakes and St. Lawrence Valley. On a smaller scale the Chinook or other foehn winds of the west and the Tehuantepec winds of southern Mexico also reach gale force.

A comparatively long stretch of the coastline meets Bailey's criteria for classification as a fog belt. This belt extends from the Aleutians along most of the Arctic coast, around Newfoundland to

New England. A second fog belt is found in the summer months along the eastern periphery of the Pacific high-pressure belt, i.e., along the coast of California. Although there are occasional widespread areas of fog inland, the frequency of occurrence does not warrant classification as a fog region.

5. Australia, New Zealand and Pacific Island Areas (Oceania)

Australia, the smallest of the continents, is probably the second warmest, extending as it does from the south edge of the equatorial belt to the north edge of the subpolar low-pressure belt. Its climates range from the rainy tropical of the northern peninsulas through the arid center and west to the rainy marine of Tasmania. The islands covered in this discussion extend over the same latitude belt, but their climates are all rainy. New Zealand extends from the center of the South Pacific high-pressure belt well into the subpolar westerlies. The balance: New Caledonia, New Hebrides, and Fiji, all lie in the tropics.

Temperature distribution over this region is the most uniform of that of any of the continents. Mean daily maximum temperatures in the warmest month barely exceed 100° F. in the warmest portion,

the northern part of the arid interior, although temperatures to 120° F are experienced. Mean daily minimum temperatures below freezing in the coldest month occur in only a few isolated points on South Island, New Zealand. No case was noted of a daily minimum temperature below 15° F. Temperatures over most of the area range from the thirties to sixties in winter, to sixties to nineties in summer.

Frequency of occurrence of precipitation in New Zealand and the southern portions of Australia is remarkably uniform throughout the year with rain falling nine or more days per month. Elsewhere, precipitation is mostly seasonal with zero to three inches per month in the arid regions up to 0.1 to 18 inches per month in the tropical rainy regions of the north. The interior and western arid regions receive 4 to 10 inches per year, considerably more than the hyperarid Sahara.

Although the northern portion of Australia, the New Hebrides, and the Fijis all experience very high relative humidities a large portion of the year, they do enjoy at least a short period with comparatively low humidities during the dry season. Humidities in the sou... portion of Australia and in New Zealand vary continually

between approximately 50 per cent between storms to 95 per cent in periods of storms. Elsewhere in the region, humidities are generally in the middle to low ranges except during brief humid periods in the local storm seasons.

The maximum thunderstorm activity occurs characteristically in the tropical air masses as they flow over the continent, or in the vicinity of the inter-tropical convergence zone. Maximum frequency of occurrence on the northern tips of Australia is approximately 100 days per year. However, maximum frequency of occurrence in the tropical islands of Fiji and the New Hebrides is only 25 to 35 days per year. In the southern rainy areas thunderstorms occur only about 10 to 30 days per year, and in the central arid region they occur about one to 15 days per year.

No data were available on frequency of occurrence of sand and dust storms. It is known that they do occur in central and western Australia. It is probable that the frequency of occurrence in these areas is not high since the sparse vegetation acts as a binder and critical wind speeds are attained infrequently. These storms are probably not a serious factor in Australia.

Although influenced in the usual manner by terrain features, the wind patterns over Australia and the various islands are the least complicated of any of the continental regions. The southern half of Australia and most of New Zealand lie within the belt of subpolar westerlies and experience westerly winds most of the time. The northern half of Australia and the other island groups are in the subtropical or trade wind belts and experience winds from the east or southeast the majority of the time.

Wind speeds in Australia are generally quite low in the northern portion, increasing with increased latitude to a maximum along the southern rim of the continent. Here, gale-force winds occur as much as 12 per cent of the time during winter months and occur at least occasionally in almost every month of the year. New Zealand similarly experiences a high percentage of gale-force winds during winter months. During summer, gale winds occur up to five per cent of the time on South Island. Except during the hurricane season, the island groups of Fiji, New Hebrides, and New Caledonia seldom experience gale-force winds. Since these islands lie on the equator side of the subtropical high-pressure belt, wind speeds generally run between five and 15 knots.

Although fog does occur both along the coast and inland in Australia and New Zealand, frequency of occurrence is too low to meet Bailey's criteria as a fog zone.

6. Antarctica

Antarctica lies almost entirely within the Antarctic Circle. For this reason it is almost totally covered with ice and contains, other than penguins, only a few of the lowest forms of plant and animal life. The continent is ringed throughout most of the year by an ice shelf as shown in Figures 10 and 12 following page 85. This ice shelf effectively increases the size of the continent by providing more reflective and radiative surface and by preventing approach by sea to most of the shore line. The effect of location and of type of surface is to provide the most uniform climatic distribution found on any continent.

Little quantitative climatic information about Antarctica is available. Two or three years of records from a few observing stations plus the records of a few expeditions provide our e[illegible]re store of information. Some [illegible] is obtained from the observations made on whaling vessels and on the few subpolar islands. The information

tabulated in Appendix A summarizes these few data. The blank spaces in the table indicate the lack of any basis whatever for making estimates of those particular parameters.

Temperatures over the Antarctic continent are below freezing most of the time. Only in the coastal areas do they rise above the freezing level and then only during the summer months when the mean daily maximum reaches approximately 37° F. Mean daily maximum temperature over portions of the high interior plateau probably never exceeds 0° F. The mean daily minimums vary from slightly below 0° at the more exposed coastal points to as low as -70° F in the interior. The lowest temperature ever observed is -125° F at the South Pole.

Measurement of precipitation on the Antarctic continent is very difficult because it almost always falls as snow, and it is impossible to distinguish between falling snow and blowing snow or to measure the difference between the two. However, it is probable that the maximum precipitation any place on the continent in [illegible] month is not over three inches, [illegible] equivalent. Precipitation in the driest months probably [illegible]

than 0.1 inch. Frequency of occurrence of precipitation or of blowing snow runs as high as 31 days per month during the so-called wet season, and it seldom drops below five days per month in those areas for which records are obtainable.

Few statistics are available on relative humidities, largely because of the difficulty of measuring these at the low temperatures. Absolute humidities are, of course, very low most of the time.

The coastal areas of the Antarctic continent can easily be classified as windy. The continent is surrounded by the subpolar low-pressure storm belt and so is usually ringed by a series of storms. The result is a high frequency of occurrence of gale-force winds. This frequency has been reported as approximately 30 per cent in some areas and is seldom lower than three per cent even in the calmest of months. More variation is found in wind speed in the interior regions where wind drops off to calm a high percentage of the time because of the formation of strong surface inversions in winter months. Occasional storms and the catabatic winds down the gradual slope to the coast from the polar plateaus combine to

produce wind speeds over ten knots a high percentage of the time during a portion of the year. Gale-force winds probably occur as high as ten per cent at some interior areas during these same months.

Blowing snow is probably the outstanding phenomenon of the Antarctic continent. One station reports blowing snow occurring on as many as 128 days per year. Since wind speeds of 15 knots will raise fresh snow and 25 to 30 knots will raise older snow, blowing snow is a possibility at nearly any time of year at nearly any place on the continent.

Bailey has made no attempt to determine the frequency of occurrence of fog on the Antarctic coastline, and so he has made no classification in this respect. Ice fog can and does occur during periods of low wind velocity at almost any place over the continent. The relatively shallow layers of dense ice fog reported at McMurdo Sound are probably typical of those that occur elsewhere. Since stronger winds tend to dissipate these fogs, the frequency of occurrence probably is lo in the belts of strong winds.

(3) Climatic Features Of World Ocean Areas

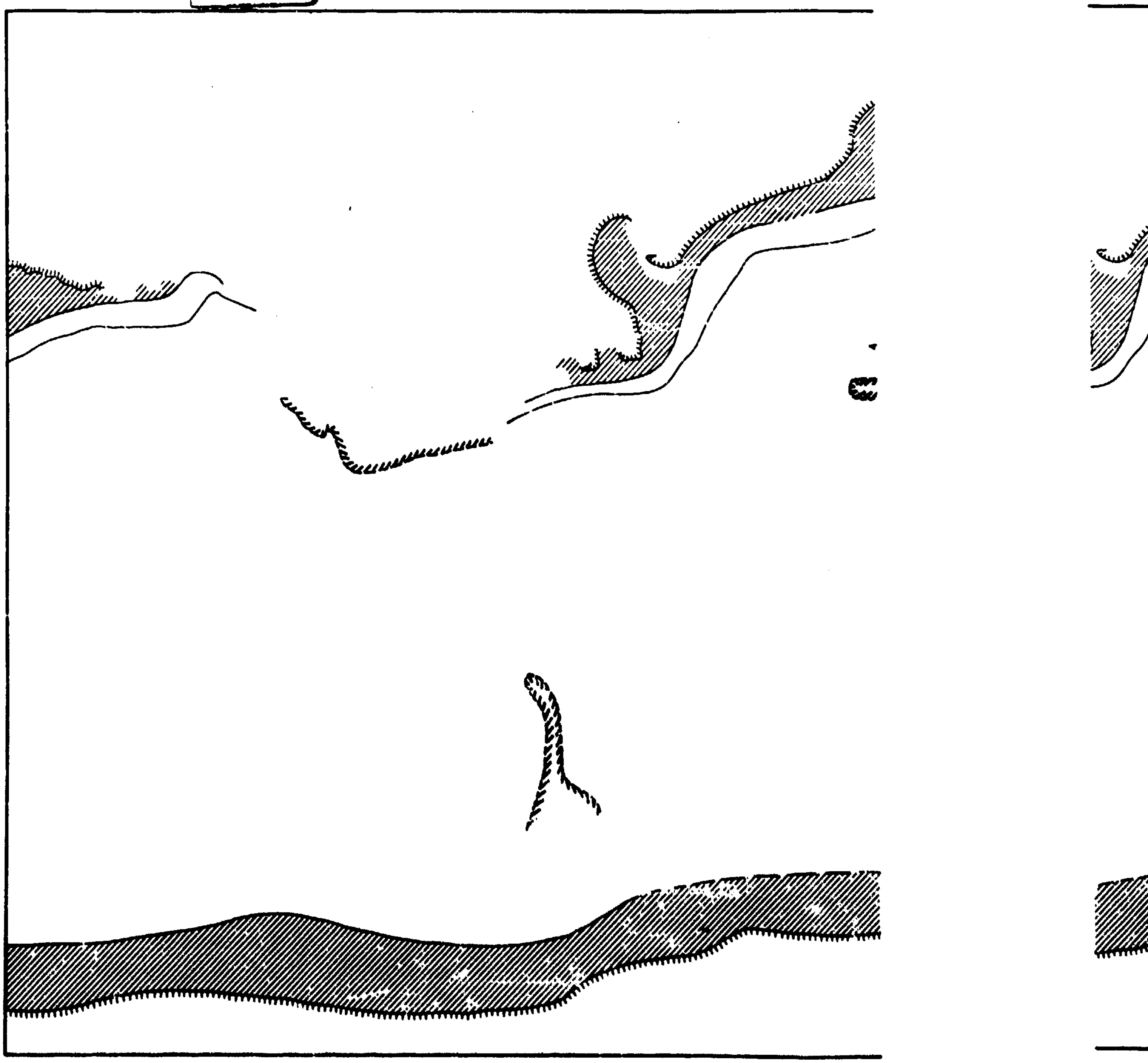
For all practical purposes the general atmospheric circulation over the oceans consists of three main streams, (1) the tropical easterlies and/or trade winds found between the equator and 30° to 40° latitude, (2) the mid-latitude westerlies, also known as the circumpolar zonal flow, found between about 35° and 53° to 70° latitude, and (3) polar easterlies. These three circulations are a result of the subtropical high-pressure belt over the oceans, whose mean axis oscillates between 30° and 40° latitude; of the subpolar storm or low-pressure belt whose axis varies between 45° and 70° latitude; and to a lesser extent of a polar high-pressure cell. The tropical easterlies and trade winds are found on the equator side of the high-pressure belt, the zonal westerlies between the high-pressure belt and the low-pressure belt, and the polar easterlies on the poleward side of the low-pressure belt. In the northern hemisphere these pressure systems are generally located in lower latitudes during the winter, when the lows are generally most intense and highs may be weakest. During the summer they migrate toward the poles, and the lows weaken markedly as the highs become stronger. The changes are not so pronounced in the southern hemisphere.

Storms in the northern hemisphere usually move northeasterly or easterly from their point of generation off the east coasts of continents to their point of maximum intensity and/or dissipation in the Gulf of Alaska or the vicinity of Iceland. In the southern hemisphere storms tend to move southeastward or eastward either to semi-permanent lows in the Ross or Weddell Seas or to continue on around the periphery of the Antarctic continent.

Tropical cyclone generation usually occurs toward the western side of oceans in the low latitudes, particularly between 10 and 20 degrees from the equator. They then normally move on westward, gradually recurving toward higher latitude, frequently along the east coasts of continents, until they move into the subpolar storm belt.

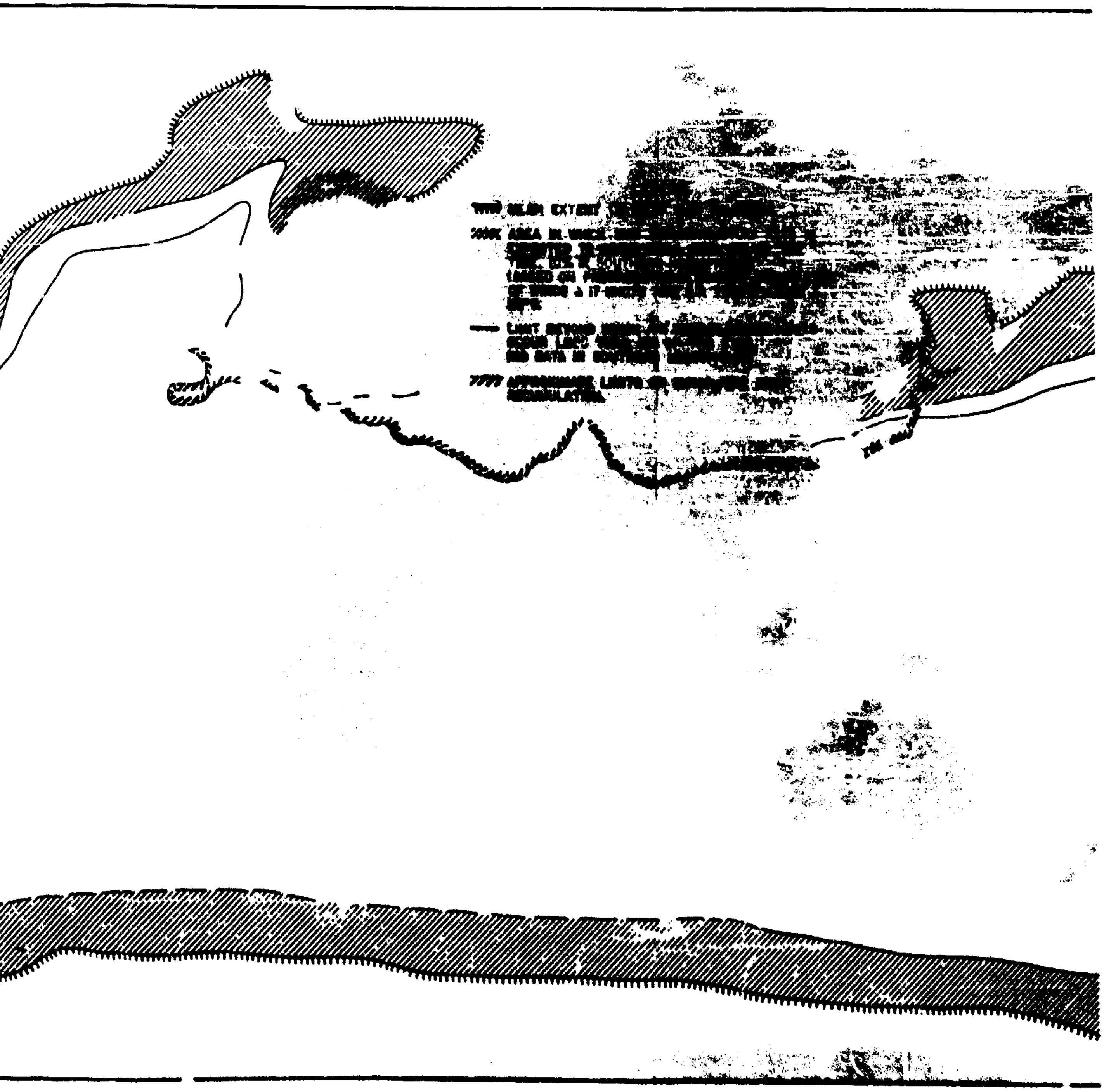
A feature of individual cells in the high-pressure belts is the subsiding, and hence very stable, air found on their east ends. The resulting lack of precipitation is responsible for the arid regions on the western edge of adjacent continents. Since the flow around the high adjacent to the continent also results in an upwelling of cold water along the coast, fog and low clouds are also characteristic of such regions. As the flow continues on around the equatorial side of the high, the air acquires heat and

1

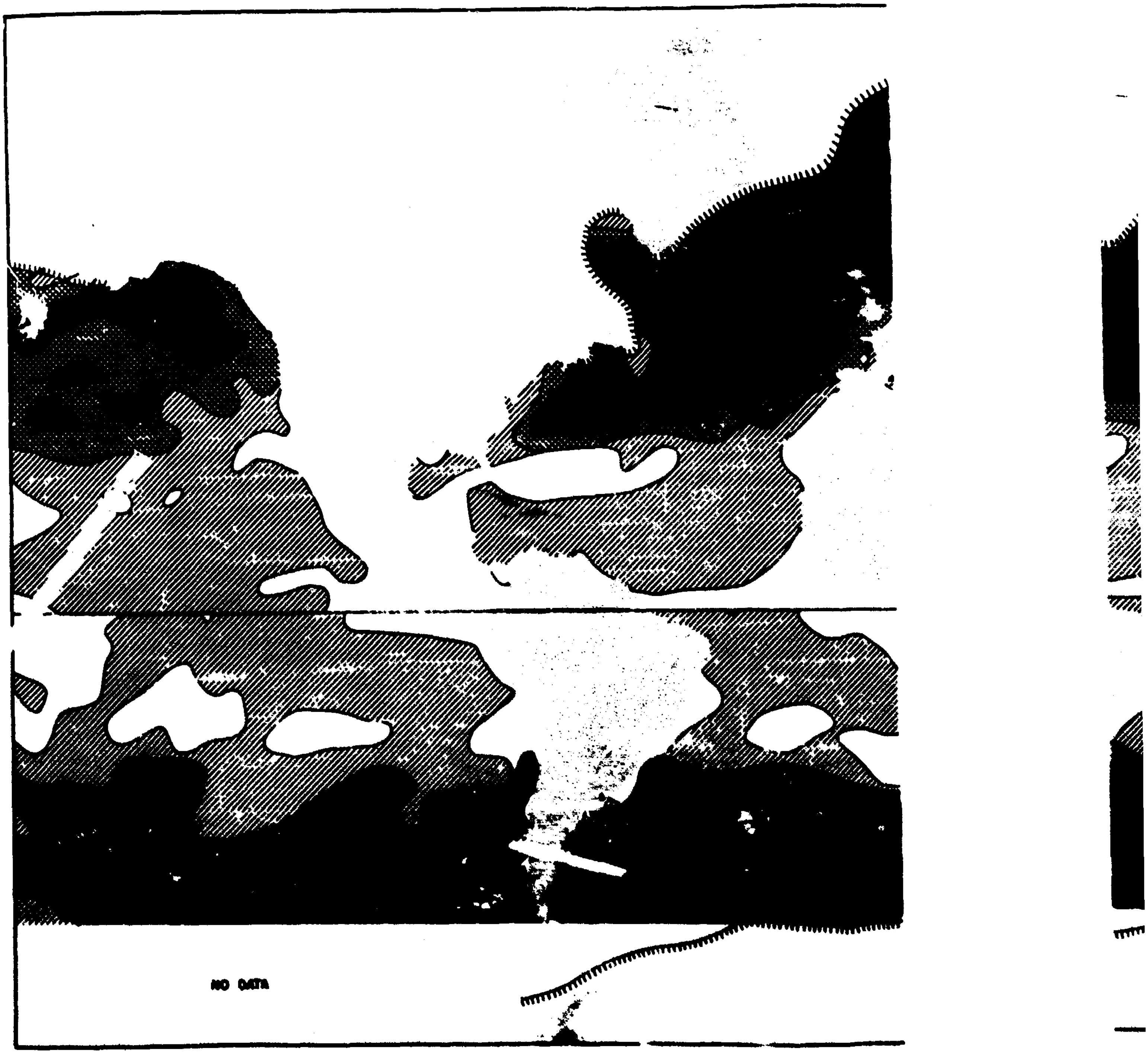


2

FIGURE 8
Mean Extent of Shelf Ice, Superstructu
Icing, Freezing Air Temperatures
and Snow--Winter

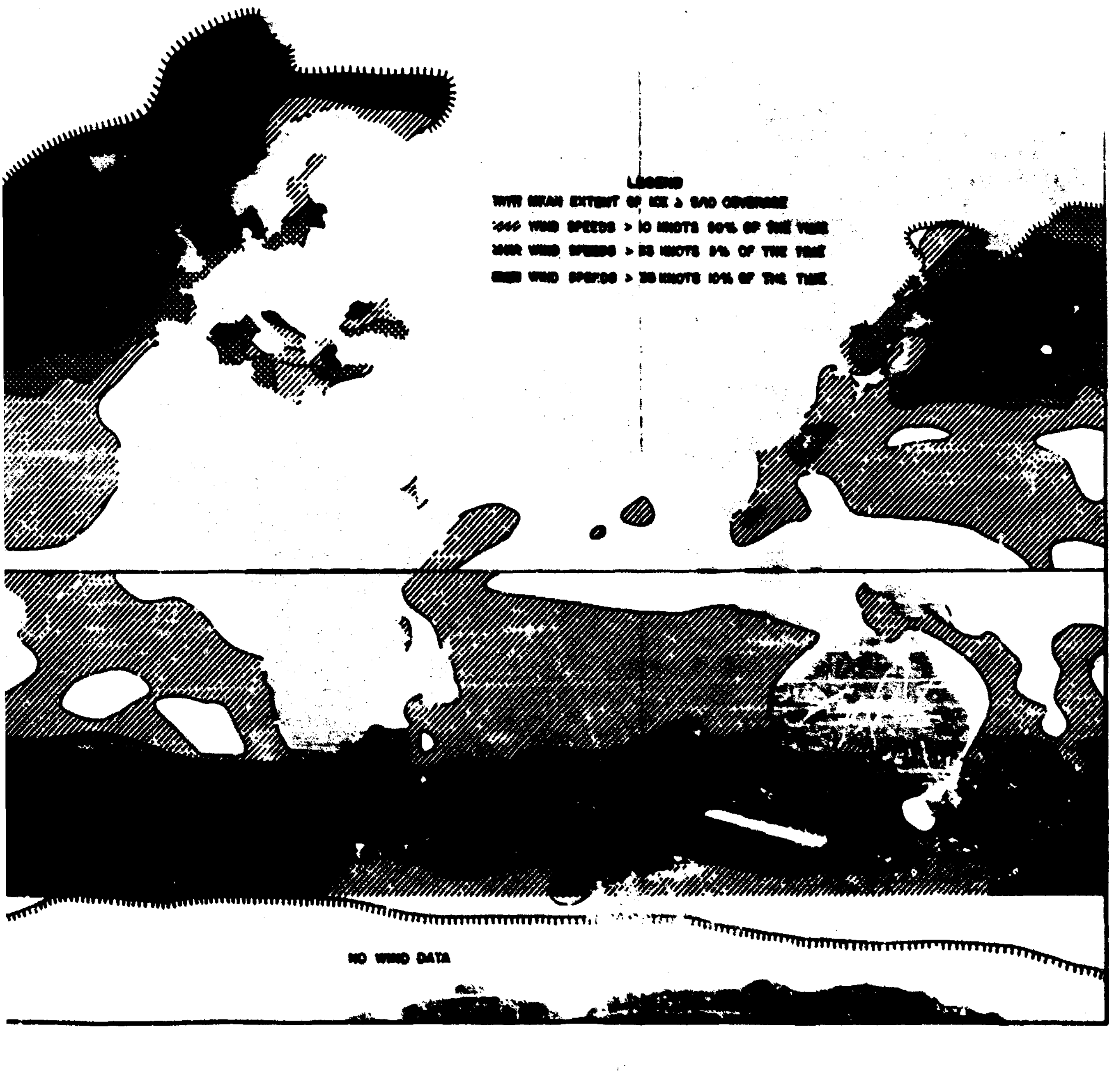


1



2

FIGURE 9
Frequency of Wind Spee[illegible]
Categories--Winter



1

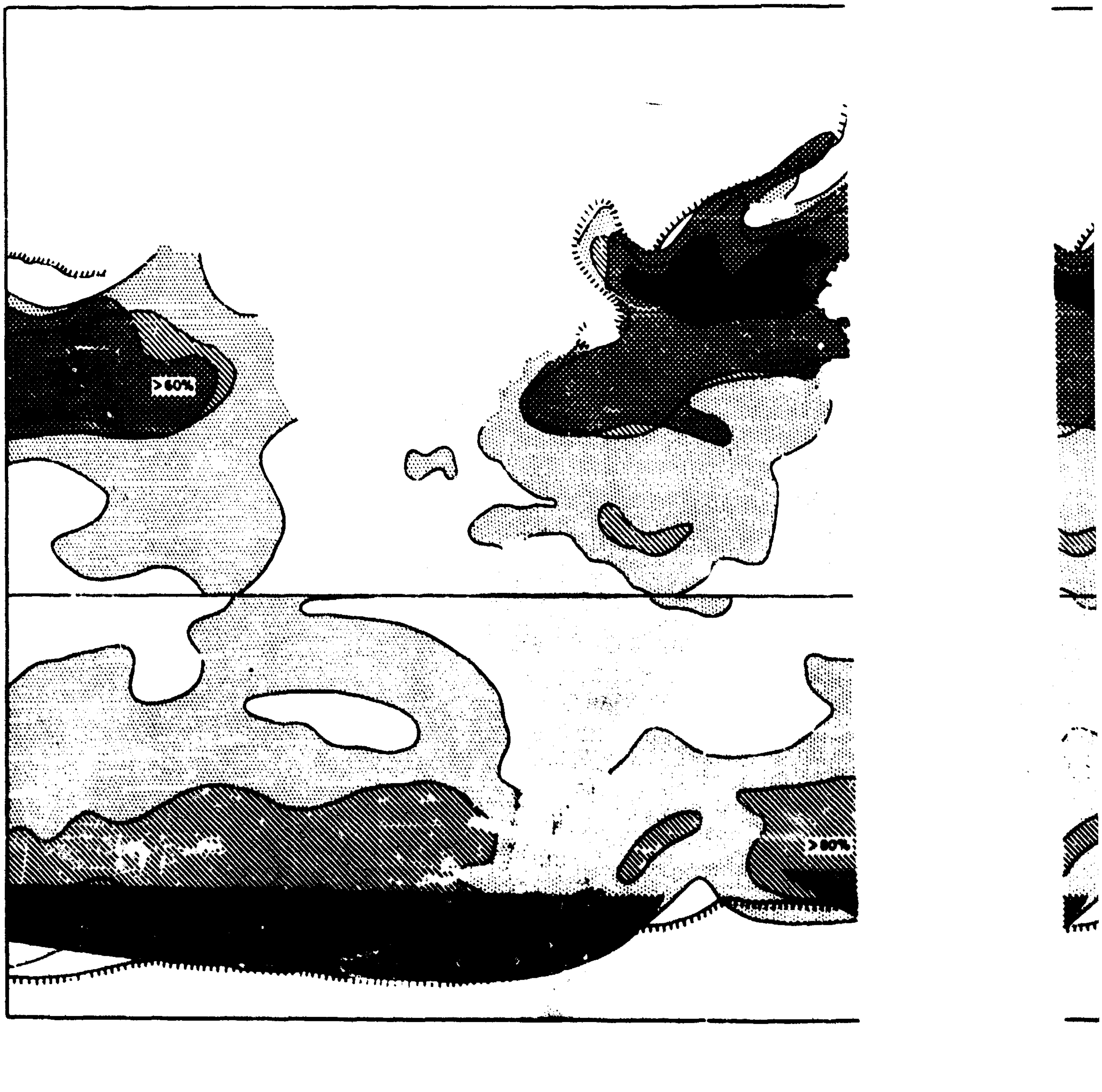
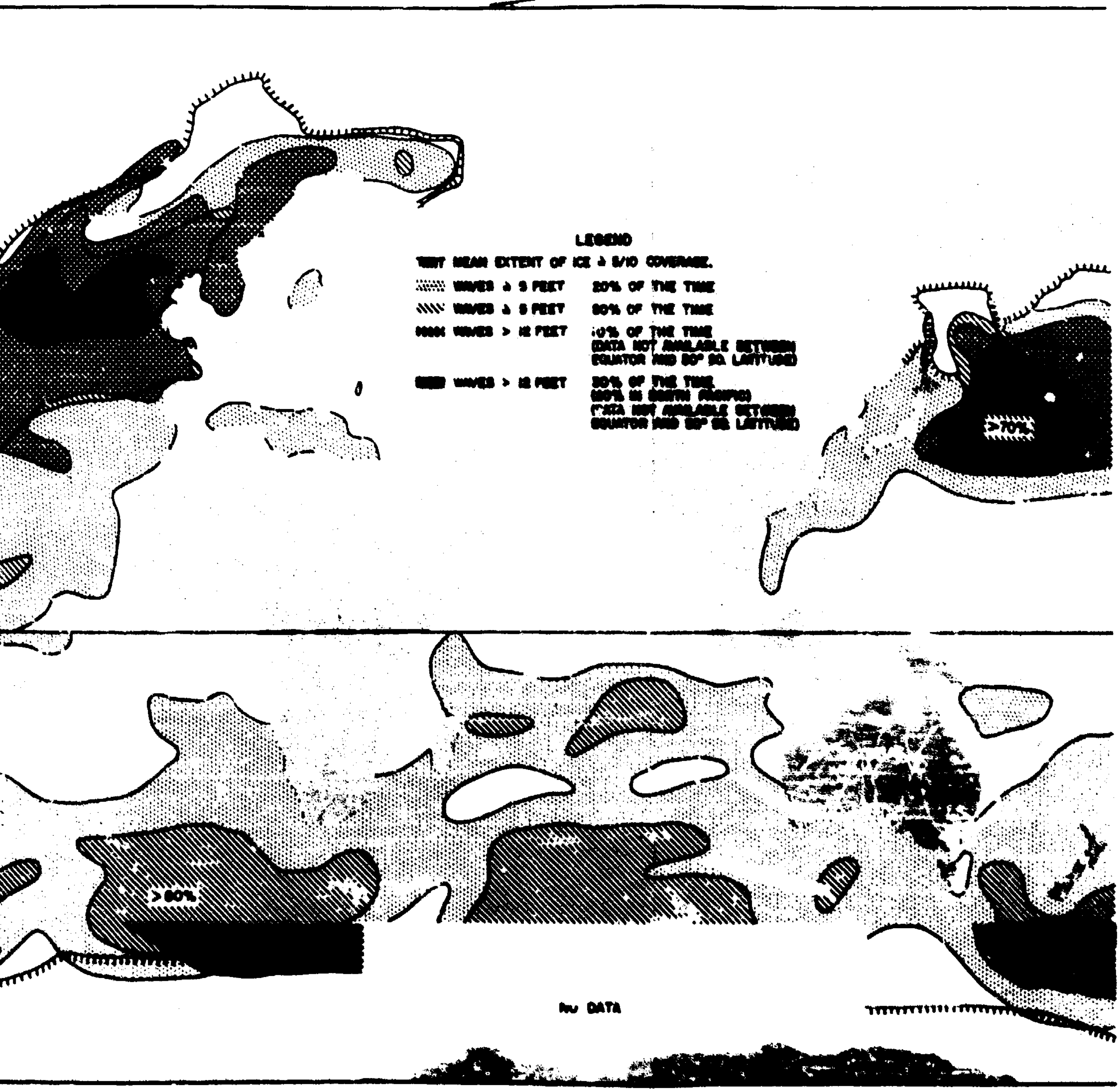
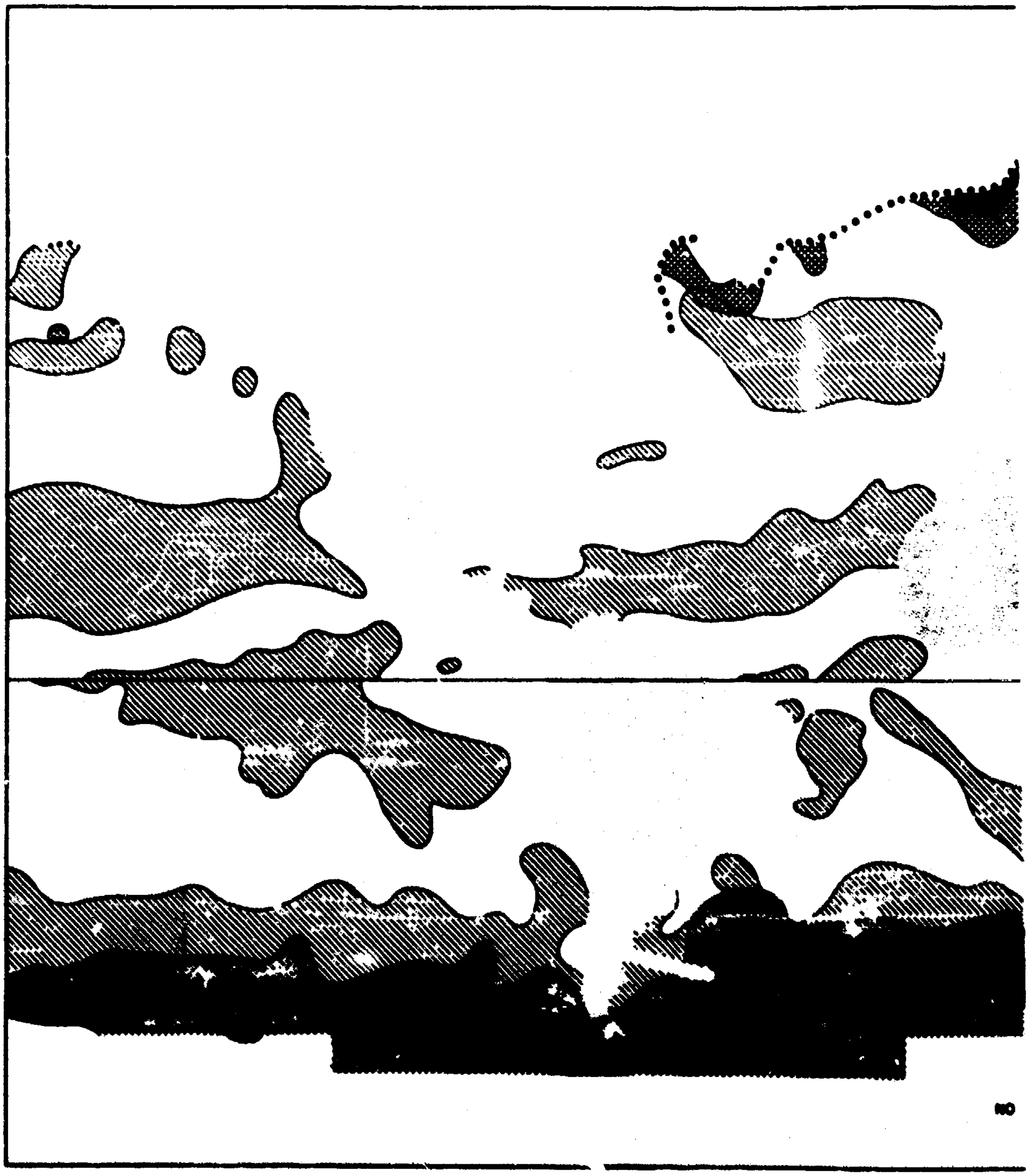


FIGURE 10
Frequency of Occurrence o
High Seas--Winter

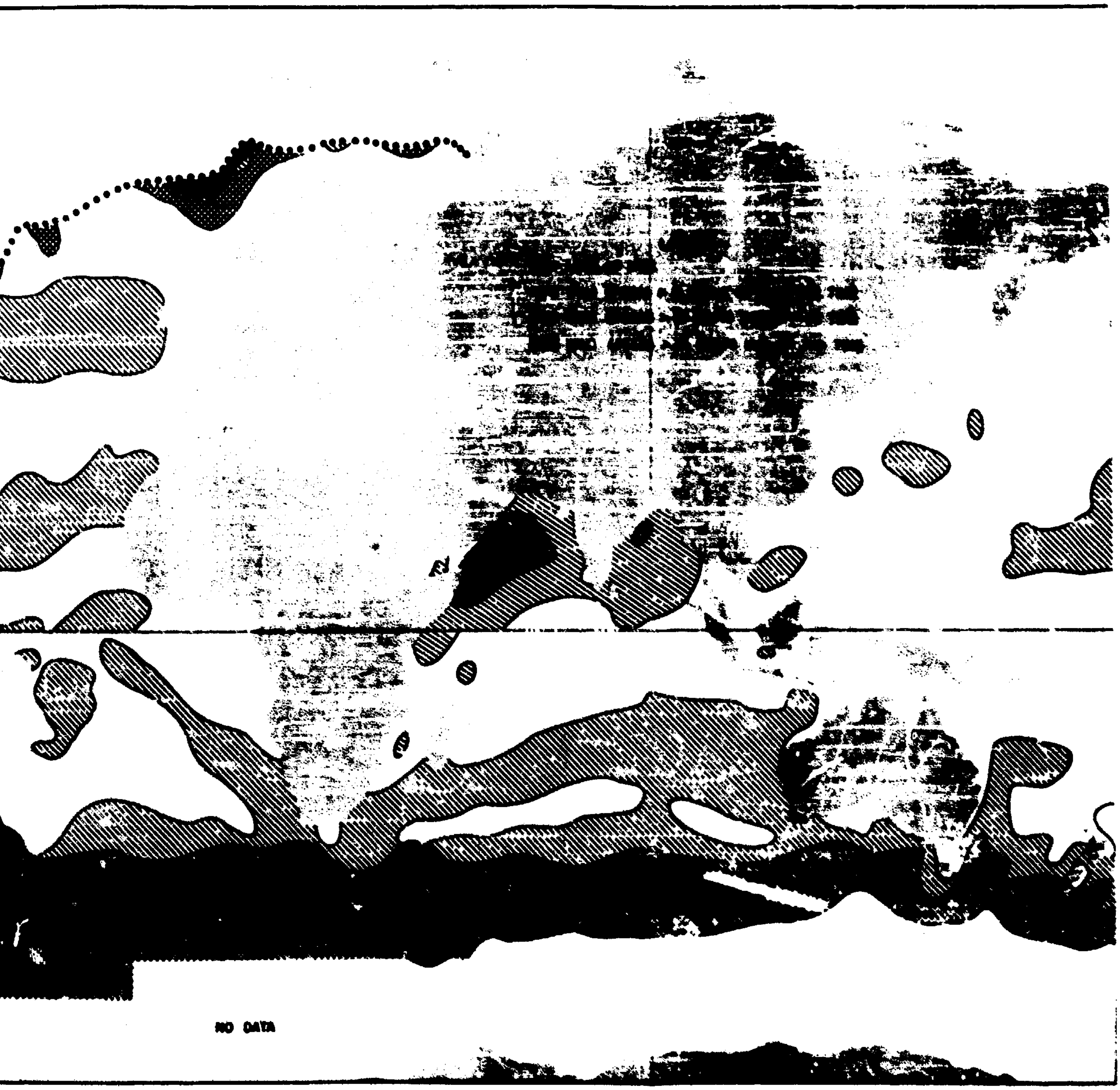


1

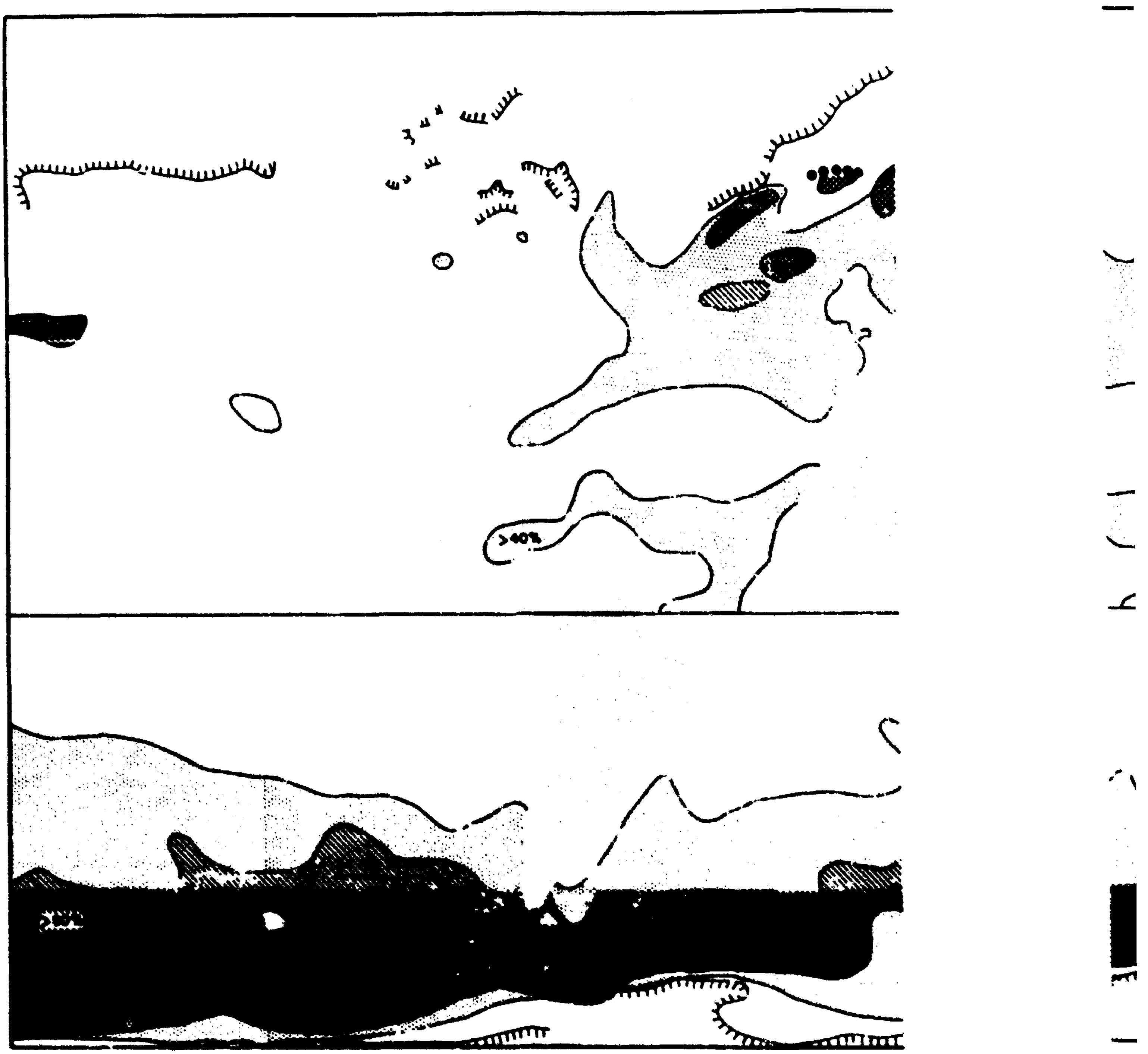


2

FIGURE 11
Frequency of Wind Speed
Categories--Summer

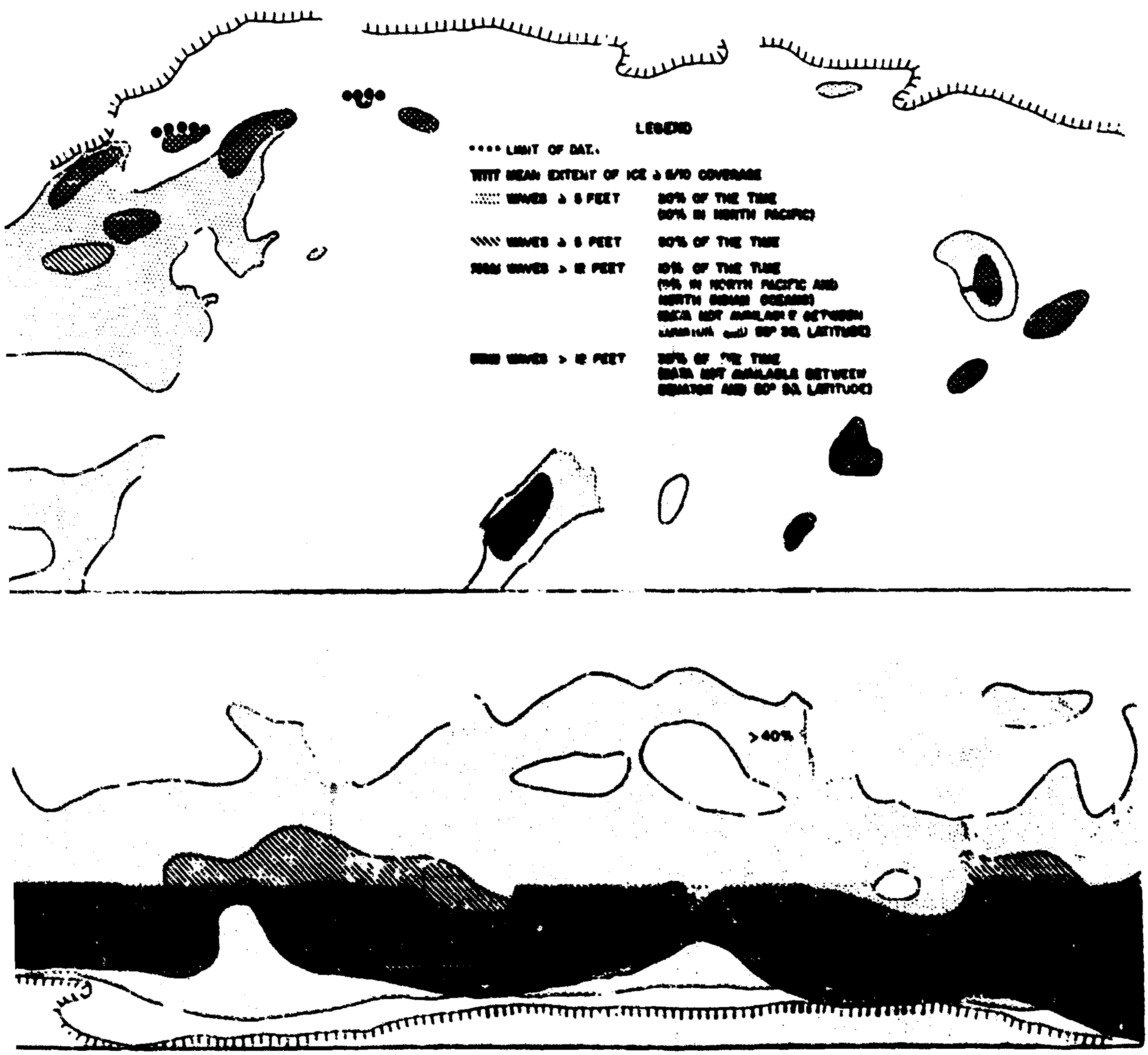


1



2

FIGURE 12
Frequency of Occurrence
High Seas--Summer



Figures 9 and 11 show the distribution of wind speeds in the winter and summer hemispheres, and Figures 10 and 12 show corresponding wave height information. In each of these figures the northern and southern hemispheres are separated by six months, i.e., the winter hemisphere may represent conditions in February in the northern hemisphere and in August in the southern hemisphere.

1. North Atlantic

The general southwest to northeast orientation of winds, waves and sea ice along the west side of the North Atlantic is an indication of the strong influence of the warm Gulf Stream. This stream is responsible for the mild climates of the more northerly latitudes of western Europe. It is also largely responsible, together with the contrasting frigid character of the adjacent polar regions of North America, for intensification of the storms which tend to follow it northeastward. It can be noted in Figures 9 through 12 that the storm activity is reflected in the regions of maximum magnitude and frequency of occurrence of waves and wind speeds.

The mean maximum extent of sea ice concentration of five-tenths or more, indicated on Figure 8, means that ice in lesser concentrations does penetrate farther south, although it melts rapidly if it enters the edge of the Gulf Stream. The ice pack recedes far to the north in the summer, but icebergs breaking off of glaciers drift out into the shipping lanes along the Gulf Stream.

The major storm tracks in the Atlantic extend from the east coast of the South Atlantic States, northeastward past Newfoundland to the vicinity of Iceland. The corresponding belts of maximum winds and wave heights extend from the area southwest of the New England coast northeastward to the 50th to 60th parallels to the tip of Greenland and Great Britain. Wind speeds and wave heights decrease to the southeastward to a minimum extending from Gibraltar westward into the Gulf of Mexico.

In the summer the boundary of freezing temperatures, along with the ice shelf, recedes far to the north. Freezing temperatures that occur less than five per cent of the time at any point in the North Atlantic. Because of this

warming, superstructure icing does not occur in the summer months. The major storm tracks are found only slightly to the north of their winter position, but the storms themselves are generally much less intense. The area of high winds and waves remains nearly stationary, although the incidence of gale force winds is considerably lower than in the winter period. Wave heights greater than twelve feet seldom occur south of the 40th parallel in the summer, and wave heights above five feet occur along the 30th parallel only about 10 per cent of the time.

2. North Pacific

The southwest to northeast orientations of the boundary between freezing and non-freezing temperatures and of the zone of probable superstructure icing found in the North Atlantic in winter, are also observed in the North Pacific, although their northward displacements there are not so pronounced. Lack of an oceanic current in the Pacific as warm and strong as the Gulf Stream in the North Atlantic results in less pronounced warming over the northeast corner of the ocean. Contributing to the observed orientation is the strong outflow of cold air from the Asiatic mainland.

Unlike the North Atlantic, there is no sea ice in the North Pacific. The most southerly advance of the ice shelf is into the southern Bering Sea, from which it recedes in the summer to the Arctic Ocean. Small areas of pack ice do form in the sea of Okhotsk and portions of the Japan Sea.

The outflow of polar or arctic air masses from the continent of Asia is even more pronounced than from eastern North America. This air contributes to the genesis of the severe storms that form along the coast and move east-northeastward south of the Aleutian chain into the Gulf of Alaska. A second major storm track extends from the central North Pacific northeastward into the Gulf of Alaska or onto the coasts of Canada and northwestern United States.

The center of the region of heavy seas and strong winds just east of Japan and south of Kamchatka (Figures 9 and 10) corresponds to the first of the major storm tracks. Here, seas greater than 12 feet occur over 20 per cent of the time. This region extends eastward into the Gulf of Alaska with a tongue southeastward to

the northeast of Hawaii that reflects the secondary storm tracks from the central Pacific. The magnitude and frequency of occurrence of high winds and heavy seas decreases toward the southeast and south. Lightest winds seem to occur in a belt that coincides roughly with the axis of the belt of high pressure across the Pacific, extending from the Hawaiian Islands area westward almost to Formosa, thence southward through the Philippines to join with the equatorial doldrums. Similarly, the most frequent occurrence of waves under five feet in height are found in a low latitude belt with arms extending northward in the vicinity of the Pacific coast of North America and to the north of the Caroline and Marshall Islands. Wave heights are also generally low in the unfrozen portion of the Bering Sea.

In the summer months temperatures below freezing occur only in small areas north of 68° North Latitude. Hence, no superstructure icing may be expected during the summer anywhere in the Pacific.

Storm tracks in the summer months differ little from those of winter, although the storms are much less intense. Storms form off the coast

of Japan and occasionally in the Yellow or China Seas. Many of these move in through the Bering Sea across to the northern tip of Alaska, but a few form in the central Pacific to move in on the coast of Washington and British Columbia. These less intense summer storms result in a much lower frequency of occurrence of gale-force winds, the maximum being reached in the vicinity of the Aleutians. The Aleutians also mark the center of the region of most frequent occurrence, 10 per cent of the time, of waves over 12 feet. This belt extends from Japan through the Aleutians on into the Gulf of Alaska. A minor maximum of these waves is located west of the Canal Zone, and they sometimes occur off the California coast.

The center of maximum frequency of occurrence of waves over five feet in height is located southwest of Kamchatka and extends eastward into the Gulf of Alaska and down the coast to central California. The central California maximum is a product of the strong high pressure cell that exists to the west during the summer months. Still another small maximum occurs along the China coast.

As in the wintertime, the mid-latitude belt of the lowest wind speeds, and consequently lowest seas, corresponds to the axis of the high pressure system which, in the summer, is found between 30° and 35° North Latitude. This belt of low seas and low winds then dips southwestward to the minimum just north of New Guinea where it joins with the equatorial doldrums.

3. South Atlantic

The relative positions of land and water in the northern hemisphere are essentially reversed in the southern hemisphere with a resulting simplification in the distribution of the patterns of the climatic elements as shown in Figures 8 to 12. The Antarctic continent, centered almost on the South Pole, is surrounded by an ice pack, which in the winter extends out to about 65° South Latitude in the Pacific and 56° in the Atlantic, and in the summer recedes almost to the shoreline.

The southern hemisphere belt of superstructure icing extends outward several hundred miles from the edge of the ice pack. Such icing can occur at any time of the year, but the probability of occurrence in the summer is much

lower than in the other seasons. The mean position of the boundary of the freezing air corresponds roughly with the outer edge of the superstructure icing belt.

In the winter the belt of strong winds and heavy seas arches across the South Atlantic from south of the southern tip of Africa west-northwestward to the center of the ocean and then southwestward to the tip of South America. Gale winds occur in this belt approximately 20 per cent of the time and winds less than ten knots occur less than about 10 per cent of the time. Seas in this belt are five feet or greater from 50 to 80 percent of the time and are greater than twelve feet over 50 per cent of the time. A band of light winds occurring 50 per cent or more of the time coincides with the axis of the South Atlantic high pressure cell between 20° and 30° South Latitude. Light winds also occur along much of the coasts of Africa and South America and in the doldrums near the equator.

The summertime axis of high winds and heavy seas is only slightly further [illegible] than it is in the wintertime. However, the frequency of

gale winds drops off to about 10 or 12 per cent, the frequency of seas five feet or greater drops off to 40 to 70 per cent and the frequency of seas twelve feet or greater drops off to 20 to 30 per cent. Winds and seas decrease markedly to the north, those winds near the South Atlantic high-pressure cell at 20° to 30° South Latitude being under ten knots nearly 70 per cent of the time. Along the equatorial coast of both Africa and South America they are less than ten knots as much as 95 per cent of the time. Seas of greater than five feet occur less than 10 per cent of the time north of the 25th parallel.

4. South Pacific

The belt of maximum winds across the South Pacific in the wintertime extends approximately east-west from the coast of Chile to the southern tip of South Island, New Zealand. One maximum of frequency of occurrence of gales (over 20 per cent) is located on the 40th parallel and a second is located on the 53rd parallel just off the coast of Chile. The belt of highest frequency of occurrence of wave heights five feet or greater coincides with this belt of gale winds. From this belt both seas and winds decrease southward

to the ice pack and northward to the equatorial doldrums. North of 20° South Latitude, wave-heights exceed five feet only about five to 20 per cent of the time.

In the summertime gale-force winds occur about 10 per cent of the time in a band between about 50° and 55° South Latitude, and the axis of the belt of high seas lies about on the 55th parallel. Here, seas greater than five feet occur 70 to 80 per cent of the time and swells greater than twelve feet between 40 and 70 per cent of the time. As in the winter, both winds and seas moderate both to the south and the north. The belt in which winds are most frequently ten knots or less extends across the Pacific from the 20th parallel on the east side to the 15th parallel on the west side. However, lowest wind speeds occur along the northern half of the South American coast and in the western extremities of the tropical Pacific

5. Indian

The east-west belt of gale-force winds found in the Atlantic and Pacific continues across the South Indian Ocean at between 40° and 55° south. Gale-force winds in the winter occur

from about eight per cent of the time south of Australia to a maximum of 20 per cent of the time at or near 42° South Latitude, 40° East Longitude. In the corresponding belt of heavy seas, heights five feet or greater occur from 50 to 75 per cent of the time. There is the usual sharp dropoff of winds and seas further north. A belt in which wind speeds of ten knots or less occur approximately half the time extends across the Indian Ocean at 30° south. However, the most frequent occurrence of low wind velocities is essentially right on the equator.

In the summer the position of the belt of high winds and seas shifts slightly southward, but the frequency of gale-force winds decreases relatively little. That the winds decrease in average intensity is confirmed by a decrease in the frequency of seas five feet or greater to about 40 per cent and of those over 12 feet to about 30 per cent.

The seasonal change in winds and seas in the North Indian Ocean is reversed from that of the other oceans. Gale-force winds are almost unknown in the winter, and high seas, even those of only five feet or so, occur less than two per

cent of the time. In the summer, however, the frequency of gale-force winds in the Arabian Sea just east of the east tip of Africa increases to over 30 per cent and wind speeds of ten knots or less occur less than 10 per cent of the time. The corresponding seas in this area are five feet or greater 70 per cent of the time and twelve feet or greater 10 per cent of the time. However, these heavy seas and strong winds drop off sharply toward the southern tip of India and seas of twelve feet and greater are almost unknown from the south edge of the Arabian Sea eastward to Sumatra.

(4) Summary Of Significant Climatic Features

1. Average wind speed, frequency of occurrence of gale force winds, average heights of seas, and frequency of occurrence of high seas all tend to increase with latitude to a maximum between 40° and 65°, and to be higher in winter than in summer.

2. Sea ice is an important factor in the winter in the higher latitudes of the North Atlantic and the South Atlantic, Pacific, and Indian Oceans. No significant amounts of sea ice

are found in the North Atlantic in the summer. In the summer in the southern hemisphere sea ice recedes almost to the Antarctic continent but does not disappear.

3. A belt of probable superstructure icing several hundred miles wide borders the edge of the sea ice in both hemispheres in winter. This belt disappears in summer in the northern hemisphere and decreases markedly in the southern hemisphere.

4. A belt of high pressure is found in all but the North Indian Ocean at about 30° to 35° latitude. The high-pressure cells are usually strongest in summer and weakest in winter in the northern hemisphere, but they show little seasonal change in the southern hemisphere.

5. The climate of the west coasts of continents bordering the eastern periphery of the high-pressure cells is either arid or semi-arid and experiences a high incidence of fog and low clouds.

6. A belt of low pressure exists at higher latitudes in all oceans. Storms in these belts are substantially stronger in winter than in summer. Strong, but shallow and very cold, high

pressure cells are likely to be located over land at the same latitudes in winter.

7. Africa, Australia, most of New Zealand and the majority of South America are almost free of snow and freezing temperatures, even in winter.

8. The continent of Antarctica, the island of Greenland, and portions of the northern rims of North America and Asia are perpetually snow covered, or nearly so, and are subject to blowing snow when winds exceed 30 knots.

9. The preponderance of arid and hyperarid climates are found in the northern half of Africa and in southeastern and central Asia.

10. In lower latitudes, the areas receiving the most rain and having the greatest amount of thunderstorm activity lie within the area frequented by the intertropical convergence zone (between the high-pressure celts of the two hemispheres) or at the southwest and west ends of subtropical high-pressure cells on the east side of continents. In higher latitudes the rainy areas are within the subpolar storm or low-pressure belt, particularly on the west sides of continents.

3. CONTINENTAL ENVIRONMENTS

(1) Classification of Natural Features

The development of the natural environment for overland operations of Ground Effect Machines requires consideration of the wide variety of geographic terrain and climatic elements prevailing throughout the land areas of the world. In order to provide a basis for analysis of these data, some compromise must be made between the extensiveness of the factors considered and simplicity of presentation.

Based on the unique performance and operating capabilities inherent in the GEM concept, the following basic geographic elements were considered for overland operations with Ground Effect Machines:

1. Altitude ranges
2. Slopes of surface terrain
3. Drainage features
    - a. Coastal stream valleys
    - b. Inland stream valleys
    - c. Other drainage features
4. Vegetation and surface cover
    - a. Dense forest
    - b. Brush
    - c. Gracs and meadow
    - d. Cultivation

e. Swamp and marshes

f. Other

5. Evaluation for cross-country operation of conventional tracked vehicles

6. Special features pertinent to GEM operations

The distribution of altitudes for the terrain surface was considered because of its influence on the power output of the power plants which are anticipated to be used in most GEM vehicles. The breakdown of altitude ranges was as follows:

Below sea level
0 - 1000 feet
1000 - 3000 feet
3000 - 5000 feet
5000 - 10,000 feet
Over 10,000 feet

The distribution of the slopes of surface terrain is an important element of the GEM environment. The provision of sufficient power for traversing areas of sloping surface is a significant basic design requirement for the Ground Effect Machine. The breakdown of surface terrain into regions of slope distribution was as follows:

0 - 10%
10 - 30%
Over 30%

At the present state-of-the-art of GEM development, slopes of less than 10 per cent are not anticipated to add appreciably to the installed power requirements for normal operations. Slopes of 10-30 per cent will require special consideration in the design of vehicle power installations and, in some cases, will be marginal for all operations, since the power required to navigate slopes of this range will be a significant fraction of the total power requirements. Slopes of 30 per cent and greater require the expenditure of so much power that the value of the GEM system is negated. For the present analysis, therefore, all areas where a large percentage of the slopes are over 30 per cent in gradient are considered to be beyond the range of any GEM operations.

Because of the unique capability of the Ground Effect Machine for operation over both land and water surfaces, the use of stream valleys as avenues of access to inland areas and as transport corridors in these areas is considered to be quite important in the overall GEM operations picture. Data on stream valleys reaching the coastal areas have been integrated into the other material being developed for coastal and amphibious operations. The use of inland stream valleys affords in many areas the only routes in otherwise inaccessible terrain. Data relating to these features includes the frequency of stream valleys,

the mean width, and a qualitative notation of the steepness of the banks. The frequency data were used to determine the relative accessibility of areas through stream valleys. The width data provides information on possible limitations of vehicle size; and information on steep banks indicates areas in which stream valleys can be used, but without exits to the surrounding terrains (where banks are steep and high, the GEM cannot climb out of the valley).

Special drainage features were also considered to provide additional data for operation in these areas. Among the features considered were swamps, marshes, canals, irrigation ditches, rapids and waterfalls, glaciers and ice cover, areas of intermittent streams, fiords, and areas of underground drainage (karst topography).

Data on surface cover by vegetation provides additional background for determining necessary operating heights of the vehicles. Area classified as dense forest is that where growth is too tall to fly over, too closely spaced to travel between, and of sufficient density to require large-scale clearing operations (with bulldozers and power equipment). Vegetation classified as brush does not have the height, density, or spacing characteristics of that indicated as forest. Notations as to the normal height distribution or spacing of such cover was

added to the percentage breakdown. Vegetation described as grass includes areas of savannah with widely scattered tall trees and other brush.

Cultivated areas include irrigated crops, root crops, grains, and tree crops, with a notation of the normal height of the crop during the growing season. Swamp and marsh areas include vegetation appropriate to such regions (in some cases, mangrove forest and other dense trees). Other forms of vegetation and ground cover include barren rock, ice caps and glaciers, lava flows, and desert and semi-desert vegetation, as well as areas of dunes and loose sand.

The evaluation of an area for cross-country operations provides a further check on the significance of all the preceding features, as well as one standard by which GEM capabilities could be compared with those of other vehicles. For purposes of this study, the standard unit of comparison for cross-country operations is a full tracked vehicle, exemplified by the medium tank type. Areas unsuitable for cross-country operations with tracked vehicles were specified as a percentage of the total land area within the particular geographic unit, and notation of the primary cross-country obstacles was made: e.g., steep slopes, dense forest, rough ground, etc.

In addition to all the foregoing items, special features considered to be pertinent to the operations of Ground Effect Machines have been listed in separate notations for each of the geographic units in which they are found. These features are those which will have a primary influence on operating requirements and design parameters for GEM vehicles in a given area. Primarily, they are terrain obstacles which may include cultural features such as road embankments and irrigation ditches. However, military obstacles are not included in this breakdown (for which, see discussion under Combat Environment, Chapter III). Complete discussion of these features is given in the area summaries; a few examples, however, are listed below:

Place	Feature	Useful Number
Malaya	Rubber plantations	Separation of trees 15-30 feet
Sahara Desert	Sand dunes	Lee slopes 30-60% (17°-30°)
Arabian Peninsula	Sand dunes	Lee slopes to 100% (45°)
East China	Rail and road embankments on flood plain	Height 3-6 feet above plain
Thailand	Rice paddies	Dikes 2 feet high, 3 feet wide, spaced about 100 feet. (Paddies are dry during the non-growing season.)
United Kingdom & Ireland	Hedges	Height 4-15 feet

U.K. & Ireland	Stone walls	Height 2-6 feet
Belgium & Netherlands	Irrigation ditches	3-4 feet deep by 4-8 feet wide. Larger canals 5 feet deep by 15 feet wide.
Italy	Hillside cultivation	Terraces 3 feet high, with walls 2-5 feet
Finland	Eskers	Earth ridges with slopes of 50-70% up to 100 feet high extending for 5-15 miles

Numerous other features of similar kind have been described, and are contained within the data for the specific geographic units.

The geographic data for terrain, vegetation, and the other features listed above are commonly available in terms of political units, and the data have been recorded in this manner. In order to facilitate correlation with the climatic and weather data discussed earlier in the chapter, these political units have been further broken down into the climatic zones. The data appendix (Appendix B) lists political units, climate zones, and the area of each climate zone within each political unit. This breakdown of data units allows a wider range of applications for the data element . so that analyses and summaries can be developed on any desired basis.

The remainder of this section includes a discussion of the world-wide natural environment for overland operations of military vehicles, slanted toward the Ground Effect Machine only to the extent that factors not significantly affecting GEM operations (e.g., bearing strength of soils) have been neglected. The discussion is presented in terms of continental land-mass areas. A few of the most important data elements from Appendix B have been summarized in Table 5. These elements are among those considered in the discussion; the numerical tabulation merely highlights the over-all geographic framework for overland operations.

A generalized map of world-wide suitability for overland GEM operations is given in Figure 13. This map was derived from the prepared environmental data of Appendix B. In a very general manner, it represents the areas of the world which are suitable for various kinds of GEM operations. The four categories included in the figure are:

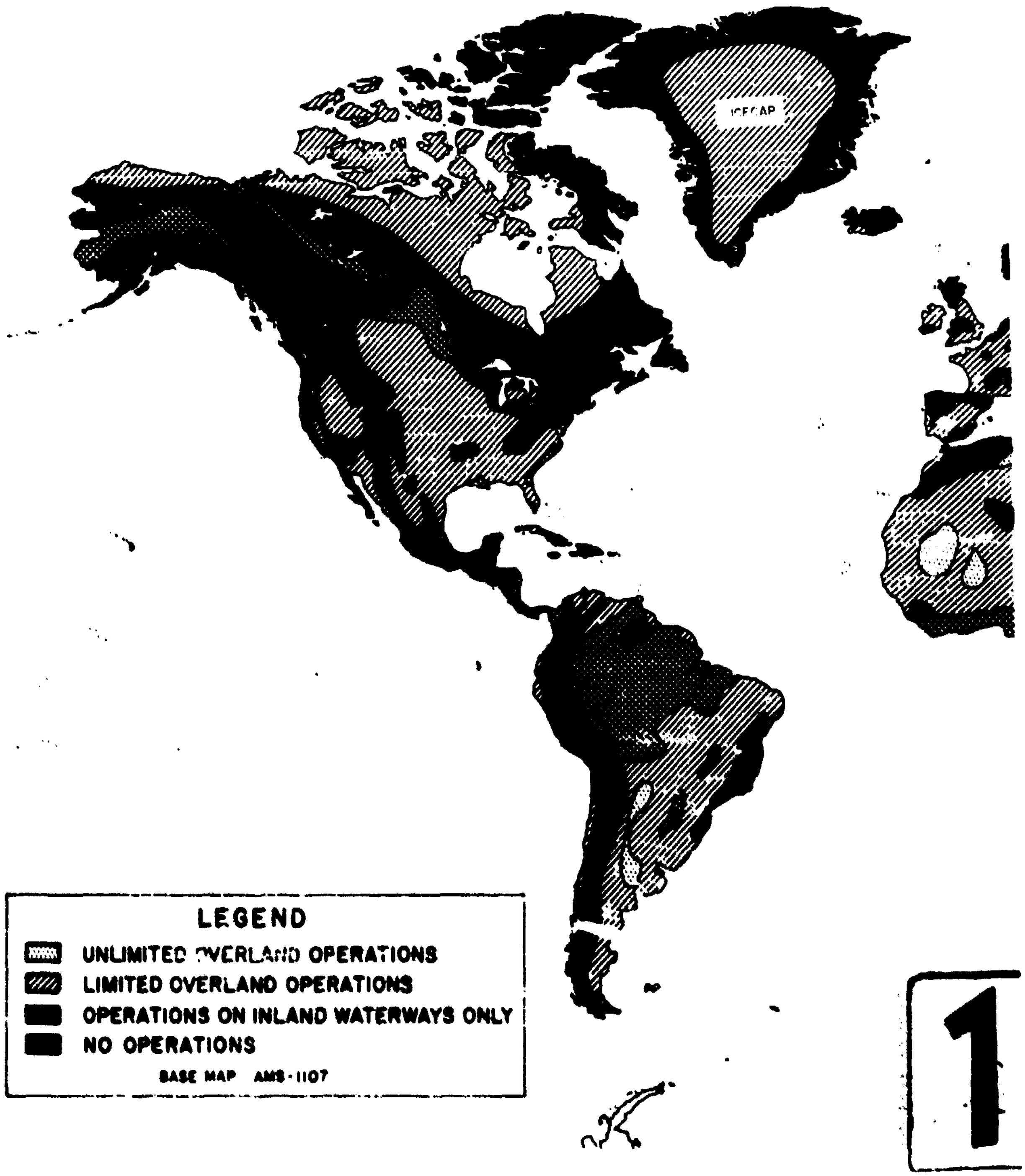
1. Unrestricted overland operations - flat lands, few obstacles, barren or grass covered.

2. Limited overland operations - flat and partly hilly lands, many obstacles, barren, grass, or brush covered, stream valleys within area at least partly usable, and banks do not form major barriers.

Table 5
Summary of Continental Environments

Continent	Area 1,000 sq. mi.	Altitude Distribution (per cent-1000 ft.)			Slope Distribution (per cent)		Vegetation & Ground Cover (percentage)			Drainage (per cent)		Cross Country Mobility
		< 5	5-10	>10	10-30	> 30	dense forest	marsh & swamp	loose sand & dunes	rivers <60 ft. wide	steep banks (inland)	% unsuitable (tracked vehicles)
Europe (excl USSR)	1,903	97.4	2.4	0.2	25.2	23.0	35	4.7	neg	~1/3	40-50	~ 50
Asia (excl USSR)	10,753	76.6	10.8	12.6	24.2	25.3	22	1.0	5.5	very few	~75	~ 45
USSR	8,650	98.1	1.8	0.1	21.5	14.8	20	5.9	2.9	very few	~60	~ 55
Eurasia	21,306	87.2	6.4	6.4	23.1	20.5	22	3.3	3.9	very few	~65	~ 60
Africa	11,733	94.6	5.1	0.3	21.0	13.2	19	1.4	8.1	very few	~75	~ 25
South America	6,883	90.5	4.6	4.9	18.2	16.7	38	2.6	neg	very few	65	~ 30
North America	9,363	81.5	17.3	1.2	27.2	25.4	32	3.3	0.2	few	50-75	~ 55
Oceania*	3,110	99.7	0.3	neg	24.2	10.1	6.2	0.3	18	?	~60 exc. few in Australia	~ 15
Antarctica	~5,500	40 ~	40 ?	20 ?	20 ?	10 ?	none	none	none	very few streams in area		~100
World	~ 57,800	85	10	5	23	18	22	3	--	--	--	~ 50

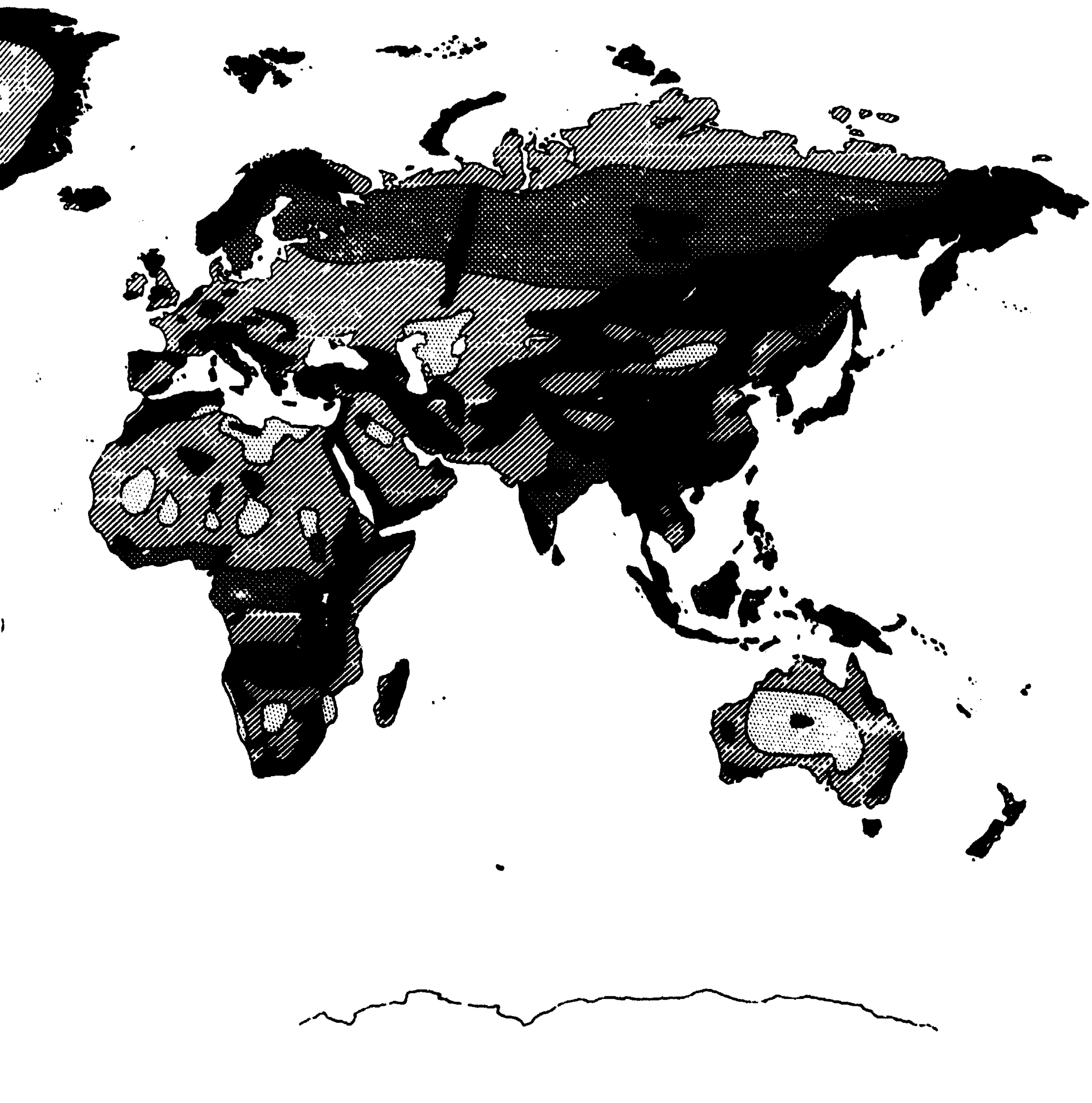
* Australia, New Zealand, and Southwest Pacific Islands



ICECAP
LEGEND
UNLIMITED OVERLAND OPERATIONS
LIMITED OVERLAND OPERATIONS
OPERATIONS ON INLAND WATERWAYS ONLY
NO OPERATIONS
BASE MAP AMS-1107
1

2

FIGURE 13
Suitability for Overland GEM Operations



3. Inland waterway operations only - forested and rough lands with wide waterways provide GEM access to most of area; GEMs will not generally be able to leave stream valleys, in some places restricted to water surface only.

4. No GEM operation - forested and rough lands, including areas of steep slopes, where GEMs will be usable only for very limited local operations.

The Antarctic region is not included in Figure 13, but in general the interior glacier areas of the Antarctic Continent will be available for limited operation of GEMs equipped with snow-removal devices, navigation equipment, and cold-weather kits. (See Induced Environment, Chapter III.)

This map is coordinated with Figure 14 following page 171 indicating suitability of coastal areas for GEM operations. Accordingly, Figure 14 should be referred to for a generalized assessment of operations in the coastal regions.

Note: Figures 13 and 14 are intended as generalized appraisals of suitability for GEM operations only, and should not be used to plan specific operations in any given location.

(2) Natural Features of World Continents

1. Eurasia

The Eurasian land mass extends through 210° of longitude and includes more than one-third of the total land area of the earth. Climate features and influences have been treated on a unified basis in Sedtion 2 of this chapter. In order to provide additional clarity in the discussion of military geography, some further breakdown of Eurasia is desirable. The old Europe-Asia boundary at the Ural Mountains no longer has much meaning because of the eastward development of the Soviet Union. In fact, the vast land area of the U.S.S.R. (more than 8.6 million square miles), and its diversities from both European and Asian neighbors leads to a convenient three-way division. This chapter, then, discusses military geography as related to GEM operations for:

Europe (without U.S.S.R.)
U.S.S.R., and
Asia (without U.S.S.R.).

This is the breakdown now being generally adopted by the geographers.

(1) Europe

Europe (without U.S.S.R.) is a compact triangular continent of just under 2 million square miles. Because of the dense urbanization and industrial development in Western Europe, cultural features have a significant bearing on the over-all military geography. Even so, the diversity of terrain and vegetation throughout Europe remains the major influence in defining the natural environment for operation of the Ground Effect Machine.

The physical geography of Europe includes an almost equal division of lowlands and highlands. The highlands consist of three belts; the northern highlands extending through most of the Scandinavian Peninsula and reappearing in the British Isles; the central highlands of eastern France, southern Germany, and southern Poland; and the southern highlands of the Iberian Peninsula, Switzerland, Italy, Yugoslavia, and Greece. Between the northern and central highlands are large central lowlands, the "heartland" of Europe. Smaller Mediterranean and eastern lowlands fill out the continent. The rugged subarctic island

of Iceland is included in the area of Europe. Its glaciers and lava flows do not allow any extensive cross-country operations.

In terms of military geography, these divisions are very significant. The northern highlands in Norway and Sweden are a rugged chain of mountains with slopes almost everywhere greater than 30 per cent. These mountains are extensively cut by fiords on the western coast, with cliffed walls rising precipitously from the water's edge. Eastern slopes of the Scandinavian Peninsula are steps down to a broad forested lowland, which includes much of Sweden and most of Finland.

In contrast to the northern highlands, the central lowlands provide very little topographic variety. In Denmark, northern Germany, Poland, the Benelux countries and western France, the terrain is almost everywhere low and gentle, with about 60 per cent of the area having slopes less than 10 per cent. The British Isles have some rough uplands but may be included in the central lowlands region.

The central highlands in eastern France and southern Germany are not as rugged as those in the northern or southern parts of the continent. In the east they become the Carpathian Mountains of Poland, Czechoslovakia, and Romania. The central highlands merge with the southern highlands in the Alps, a formidable mountain barrier extending from southeast France across northern Italy and into Yugoslavia, and containing most of Switzerland and Austria. The Alps reach 15,000 feet in height and are everywhere a severe impediment to military operations. The extensions of the southern highlands into Spain, Italy, Yugoslavia, and Greece are not as high, but just as rugged as the Alps.

In addition to a narrow coastal plain on the Mediterranean coasts of Europe, there is a densely developed lowland in the Po Valley of northern Italy, and broad, almost featureless plains in Hungary and Romania.

Numerical data on European terrain features are included in Appendix B, and summarized in Table 5. Less than 3 per cent

of Europe is situated at altitudes above 5000 feet, and this is all in mountain areas. About 90 per cent of the area between 3000 and 5000 feet altitude is also in areas of steep slopes and rugged terrain. The over-all division of slopes in Europe is: 0-10 per cent slope, 52 per cent; 10-30 per cent slope, 25 per cent; over 30 per cent slope, 23 per cent.

Drainage characteristics of Europe consist of many small rivers with a frequency of 15-40 miles. In about two-thirds of the area, these are over 60 feet wide, but in a few places they are less than 30 feet wide. Banks of river valleys are not generally steep except in mountain areas. The banks of rivers which have been canalized are mostly steep, 30-100 per cent, and up to 10 feet high. In Spain, Portugal, Greece, Switzerland, and Austria, most rivers are narrow, rocky, and have steep banks; thus, they cannot be used as access routes in these areas. Waterfalls and rapids are common on the eastward flowing rivers of the Scandinavian Peninsula, while those on the west are mostly steep mountain streams emptying into numerous fiords.

Most of the larger rivers of Europe have artificial channels and are connected by numerous canals. This network provides many water routes through France, Germany, Poland, Hungary, and the Benelux countries. Many of the canals have widths of 30 feet, with steep banks.

In western Yugoslavia and Albania is a large area of karst topography with subsurface drainage, and almost no streams. The rough surface of this area has many sinkholes and rocky areas.

Vegetation in Europe includes a dense forest belt in the north and many small forests scattered throughout the rest of the area. Dense forests cover 35 per cent of Europe, including 15 per cent in mountainous areas. The lowlands of Europe are extensively cultivated -- croplands cover more than 38 per cent of the continent. Most of the areas have vegetation cover not exceeding 4 feet high in growing seasons. Grasslands and pasture cover about 9 per cent of Europe. Marshes and bogs are common in Finland and southern Sweden, and also occupy extensive

areas in Ireland, Czechoslovakia, and Romania. There are very few desert areas in Europe, but sand dunes are common on the coasts of France, Belgium, Netherlands, and Denmark.

Because of the dense urbanization of Europe, cultural features are important in military geography. Included among these features are the many irrigation canals and ditches of the lowlands in northwest Europe and on the eastern plains. Most of these are 2-4 feet deep and 3-10 feet wide, but some are up to 10 feet deep and 30 feet wide. Earthen banks have slopes of 100 per cent. Dikes and embankments up to 10 feet high are also common. Another cultural feature is the large number of densely built-up manufacturing cities, where concentration of buildings along narrow streets is an obstacle to movement. In most areas of western Europe, the existing rail and highway networks provide good transportation routes.

These terrain, drainage, vegetation and cultural features may be tied together by an

evaluation of the over-all cross-country mobility. Using the conventional tracked vehicle as a reference base, cross-country suitability ranges from 95 per cent in Poland, down to 25 per cent in Norway and Sweden. Throughout the continent, about 50 per cent of the area is suitable for cross-country operations. The remaining 50 per cent includes steep and rugged areas -- 30 per cent of the total; dense forests 12 per cent, wet and marshy ground about 3 per cent, and other unsuitable terrain about 5 per cent.

Throughout Europe are a number of special features which may be especially pertinent to GEM operations. These include the many canals and ditches previously discussed. In northwest Europe and on the Mediterranean islands, walls and hedges are common along roads and bordering most fields. Stone walls are commonly 4-6 feet high and 2 feet wide. Hedges may be up to 15 feet high; in France some are on earth embankments. In the eastern plains, roads and railroads are often built on earth embankments. Hillsides in Italy and Greece are terraced for cultivation, with steps 2-4 feet

high and 10-100 feet wide. In Finland are a number of glacial eskers -- steep earth ridges 3-4 miles apart in the south, with slopes of 50-70 per cent and extending for 5-15 miles. The surface of Iceland is covered by rough lava flows. In almost all cases the islands off the Atlantic and Arctic coasts of Europe have no areas suitable for GEM operations except in the coastal regions.

The general military geography of Europe, with most lowland areas highly urbanized, does not offer much advantage for GEM operations. Because of the existing good transportation network, the GEM is not expected to find a major use for overland operations except in limited areas. During the spring thaw, however, many of the lowlands areas are soft and wet; and under these circumstances GEMs may be used to advantage.

(2) U.S.S.R.

The Union of Soviet Socialist Republics occupies more than one-[illegible]nth of the earth's land area. The U.S.S.R. stretches across the top of Eurasia from the Baltic Sea to the

Bering Sea, nearly 7000 miles. Its vast territory encompasses the East European Plain, the Ural and Caucasus Mountains, the frozen Siberian Plain, and rough Siberian Uplands; along most of the southern boundary are inhospitable mountainous regions. Quite apart from political implications, the vast and comparatively isolated land area of the U.S.S.R. is worthy of separate consideration in respect to the natural environment for the Ground Effect Machine.

The U.S.S.R. can be divided into five regions for analysis of military geography. The western part of the U.S.S.R. is a continuation of the part of the Central European plain. Ninety per cent of this area lies below 1000 feet and has slopes less than 10 per cent. In the south and east, there is a mountain fringe. The southern mountains, the Caucasus, form a rugged boundary between the U.S.S.R. and Turkey and Iran. The central Caucasus barrier can be circumvented by the Black Sea and the Caspian Sea.

The southern section of Soviet Central Asia is predominantly an arid lowland, bordered by mountains on the east and south, and the Caspian Sea depression on the west. This region is 25 per cent desert. The northern section of Soviet Central Asia contains the Ural Mountains, and most of the Great Siberian Plain, a vast cold lowland. Almost 90 per cent of this region has slopes of less than 10 per cent.

The eastern Siberian Uplands area, bordering on Mongolia, China, and Korea, is the largest physical division of the U.S.S.R. This region is an area of plateaus and low mountains, bordered by a frozen Arctic coastal plain. Except for this coastal plain, the Eastern Siberian Uplands are 70 per cent hills and mountains, with slopes exceeding 30 per cent in about one-third of the area.

The over-all terrain characteristics of the U.S.S.R. are broad plains mostly below 1000 feet, divided by the north-south Ural Mountains, and bordered on the south and east by rugged highlands. Of the total area of 8,650,000 square miles, 15 per cent has

slopes greater than 30 per cent, and 22 per cent has slopes of 10-30 per cent. Two per cent of the land area lies above 5000 feet, but this is mostly in mountain areas with steep slopes.

The drainage characteristics of the U.S.S.R. reflect the diversity of climates and terrain within the region. In the southern part of Soviet Central Asia most streams are intermittent and dissipate in the desert basins. Throughout the rest of the U.S.S.R. are distributed a number of large rivers from 30-100 miles apart. Most of these flow northward to the Arctic, but the Volga, Dnepr and Ural Rivers flow south to the Black Sea and Caspian Sea. Rivers are generally over 100 feet wide, except in the mountains. Banks are gradual in the plains areas, but steep in the mountains and arid regions. The north-south rivers of the U.S.S.R. are used as commercial waterways during the summer months. Rivers are frozen solid from November to May in the north, and from December to March in the south. Often the ice-covered surface is rough; ice jams form during the spring thaw.

The northern plains have many marsh areas, which are quite impassable when thawed. In addition, there are irrigation ditches along streams in the arid regions of the Caucasus and Soviet Central Asia.

Vegetation follows the climatic bands, with stronger latitudinal influence than in other regions of the world. The Arctic coastal plain is mostly covered with barren tundra or sparse brush. Adjoining this is a wide forest belt, with dense forests in the western area, and brush woods toward the eastern regions of the Siberian Uplands. Altogether, dense forests cover 20 per cent of the U.S.S.R. South of the forest belt are the grasslands of the Siberian steppe. In the western region, the steppe is extensively cultivated (50 per cent of European Russia). Scattered among the forests and grasslands are numerous marshes, 6 per cent of the total area of the U.S.S.R. These are predominantly frozen for a few months during the winter. Barren deserts and sparse desert vegetation covers the southern part of Soviet Central Asia. Twenty per cent of this region is covered by low sand dunes (3 per cent of the U.S.S.R.).

Cultural features are very limited except in the western industrial and agricultural areas. Limited irrigation features are scattered throughout the drier regions.

The over-all evaluation of the U.S.S.R. in terms of cross-country operations indicates that about 45 per cent of the area is suitable for operation of conventional tracked vehicles. The dry regions of Soviet Central Asia are generally suitable for cross-country operations. In other regions, cross-country capability ranges from 25 per cent in the rough Eastern Siberian Uplands to 60 per cent in the central plains. Summary Table 5 shows that the main factors influencing cross-country operations are steep slopes, forests, and soft ground. The Arctic tundra is suitable for cross-country operations <u>only</u> when frozen (6 to 8 months of the year).

GEM operations in the U.S.S.R. would be generally unlimited in the broad plains regions. Where the plains are densely forested in the west, river valleys could be used. The desert regions around the Caspian Sea would not provide much obstacle to GEMs Because of their low ground pressure, GEMs

could operate on the tundra even when it is thawed. By the use of north-south river valleys (either frozen or open), GEMs could reach most areas of western and central Siberia. For operations in the northern areas vehicles would need protection against the effects of cold, and special consideration of the rough ice surfaces likely to be encountered.

(3) Asia

Asia is the continent of great diversities: climate, population, economic development, and military geography. Determination of the natural environment for overland operations of the Ground Effect Machine requires integration of the climatic and geographic elements. It has been presumed, in addition, that any detailed analysis of military operations in Asia must consider the significance of the diverse population distribution and economic development level within this vast continent.

Climatic influences in Asia have been discussed in Section 2 of this chapter. The contrast between the arid interior and wet

coastal regions has a significant influence on potential GEM operations. Equally significant is the diversity of terrain and vegetation elements, which are interrelated with the climatic factors.

Excluding the territory of the U.S.S.R., Asia remains a continental land mass of immense proportions. It stretches from Turkey to Japan, from Mongolia to Indonesia; with a total land area of 10.7 million square miles, including the island fringe.

The physical geography of Asia is centered on a high central plateau surrounded by rugged mountain chains radiating east, west, and south to the oceans. East and west, the mountains form most of the boundary between the U.S.S.R. and the countries of Asia. On the west these mountains extend through Afghanistan, Iran, and Turkey, dividing the arid Arabian Peninsula from the equally arid central Asian deserts. Eastward the mountains stretch across northwest China and Mongolia. A second eastward-extending range, the Himalayas, isolate the Gobi Desert and the Plateau of Tibet

from the rest of the continent; then turn southward to form the rugged backbone of Burma, Thailand, and Indochina. Rugged highlands are prominent throughout the rest of the continent, particularly in Korea and the island fringe - Japan, the Philippines, and Indonesia. Almost everywhere the highlands descend abruptly to coastal plains which are densely forested or cultivated. A few broad lowland valleys exist in Iraq, Pakistan, India, Burma, Thailand, Indochina, and eastern China. These broad lowlands are literally filled to overflowing with humanity and densely cultivated areas.

Asia is the highest of the continents, except Antarctica, with a mean altitude of more than 3000 feet. About 11 per cent of the land area is between 5000 and 10,000 feet, 9 per cent between 10,000 and 15,000 feet, and 4 per cent above 15,000 feet. With the exception of small areas on the Iranian Plateau and the western parts of China, most of these highlands are in mountainous areas. The large rough Plateau of Tibet has an altitude of 10,000 to 13,000 feet, but it is entirely encircled by rugged mountain ranges.

The rugged backbone of Asia is associated with areas of predominantly steep slope. Slopes greater than 30 per cent are found in 25 per cent of the continental land mass, and slopes of 10-30 per cent make up 25 per cent of the area. In addition, many of the plateaus of central Asia are isolated by one or more mountain ranges. Appendix B contains altitude and slope data for all the countries of Asia, coordinated through the climate zones.

Drainage characteristics vary greatly across the breadth of Asia. Asia contains some of the great river systems of the world: Yellow, Yangtze, Mekong, Irrawaddy, Brahmaputra, Ganges, Indus, and Tigris-Euphrates. Yet, about one-third of its area either contributes no surface drainage at all, or its drainage is evaporated in interior basins.

Although river valleys form major barriers to cross-country movement in much of southern and eastern Asia, their use as potential GEM access routes is limited to a few areas. In China, the Yangtze and Yellow River drainage

basins have vast flood plains which from time to time are inundated by floods, forming areas of water and mud several hundred miles wide. Other rivers in China are generally over 60 feet wide, and separated by 30 to 100 miles except in the arid, high, western plateaus. About half the rivers in China have steep banks. In Korea and Japan, river valleys are separated by 5-50 miles, but some are not more than 40 feet wide and banks are predominantly steep. In Indochina, Thailand, and Burma, the Mekong and Irrawaddy Rivers are the primary stream valleys. Both have large flooded delta areas, extensively cultivated. Banks of these, and the many smaller rivers are predominantly steep. The rivers of India are mostly wide, many of them over 750 feet. The Ganges, Brahmaputra and Indus valleys are much used as inland waterways. In addition, they support huge numbers of people. Except in the desert area of northwest India, stream valleys are separated by 20-100 miles, with banks steep on about one-half. The rivers on the western slopes of the peninsula of India are all steep and rocky.

North and west of India, the drainage characteristics are quite different. Through western China. Afghanistan, Iran, the eastern Mediterranean countries, and the Arabian Peninsula, stream valleys are more widely scattered and most streams are intermittent. Banks of stream valleys are predominantly steep except in the sandy deserts of Iran and Arabia. A notable exception to this arid drainage is the broad Tigris-Euphrates plain at the head of the Persian Gulf. These well-controlled rivers supply a major agricultural region. Steep levees enclose most of the lower courses of the Tigris and Euphrates, and their delta area is extensively irrigated for crops. The Jordan rift valley is more of a terrain obstacle than an avenue of access, since its passage between the Sea of Galilee and the Dead Sea is entrenched in a steep, rocky gorge. Rivers on the Asian southern fringe islands -- Taiwan, the Philippines, Indonesia, and New Guinea -- are mostly between 60 and 250 feet wide and have steep banks.

Many smaller stream valleys throughout the coastal regions of Asia could potentially

be used for GEM amphibious operations, as discussed in the next section.

In addition to stream valleys, important drainage features in Asia are canals, swamps, and irrigation areas. Extensive coastal marshes are common in the Philippines, Indonesia, along the Malay Peninsula, and in the delta areas of the rivers of Indochina and India. Flood plains of the Yangtze and Yellow Rivers in eastern China are subject to inundation by flood waters. Navigation canals are important in eastern China, India, and Ceylon. These are generally over 60 feet wide, but some narrow to 30 feet at bridges. In a few areas, the lower courses of rivers are controlled by dikes and levees.

Because of the pressing need for food, most of Asia's arable lowlands are extensively cultivated in rice and other crops. Irrigation features are common in most coastal plains and river deltas. Typical rice paddy areas are divided into sections about 100 feet square, with dikes 2 feet high and 3 feet wide. The paddies are usually drained during the nongrowing season. In some places, deep

rice cultivation is used on flood plains, with dams 6 to 10 feet high retaining the flood waters. Irrigation ditches are commonly 1 to 2 feet deep and 10 feet wide, with larger canals 3 to 10 feet deep and 5 to 50 feet wide. In Thailand, canals 10 to 15 feet deep and 120 feet wide are spaced 3000-6000 feet in the lowlands, with locks at river junctions. Irrigation features are not common in the Philippines, New Guinea, and Indonesia, except on the island of Java.

Vegetation coverage in Asia reflects the climatic diversity of the region. Southeast Asia is predominantly densely forested, while the central Asian plateaus and mountains are sparsely covered with grass and brush, or barren desert. Dense forests cover 22 per cent of Asia, including most of Indochina, Thailand, Burma, southern India, Ceylon, and Malay Peninsula, and Indonesia. Scattered forest regions are found in north-east China, Korea, Japan, and Turkey. By contrast, Afghanistan, Iran, the Arabian Peninsula, the eastern Mediterranean countries, northern India, and western China

are 75 per cent covered by sparse grass or barren desert. Although dune areas and loose sand are only a small part of the desert regions, they make up about 6 per cent of the total land area of Asia. Despite the pressures of a large population throughout southern and eastern Asia, cultitated areas are restricted primarily to wet or irrigated lowlands.

In addition to irrigation features, the cultural factors in military geography are limited to the lowland plains, with a number of major cities, and numerous densely built-up "rural" communities. In the east China flood plain, railroads and roads are on embankments 3 to 6 feet high, and some cities are protected by dike and levees up to 40 feet high. Existing transportation facilities are limited to the peripheral areas of Asia. Japan and India have well-developed rail networks. Roads provide access to most parts of these countries also, as well as the China coastal areas, parts of Korea and Viet Nam, and the coastal regions of the eastern Mediterranean lands - [illegible], Lebanon, and Israel. Some of the less developed regions of Asia are entirely without highways or

railroads -- for example, Tibet, southern Arabia, and New Guinea.

In terms of military operations, all the above features may be tied together by an evaluation of suitability for cross-country operations. Using the cross-country capability of tank type vehicles as a reference base, about 55 per cent of Asia is suitable for some operation. Most of the central Asian highlands are unsuitable because of steep slopes, and much of southeast Asia is unsuitable because of forested slopes and marshy ground. Altogether, about 33 per cent of Asia is too steep for operations with conventional tracked vehicles, 10 per cent is forested or forested and rough, and 2 per cent is too wet, or has soft ground.

All these features have influence on potential overland operations of GEMs. In addition to the diverse patterns of highlands and lowlands, marshes and deserts, forests, and irrigated ricefields, a few other features peculiar to GEM operations may be mentioned. Slopes of sand dunes in the Gobi Desert range up to 60 per cent on the lee side, and likewise on the Arabian Desert and in Iran. In Afghanistan, lee slopes of sand dunes are up

to 100 per cent. Rubber plantations on the Malay Peninsula and in Indonesia commonly have trees 15 to 30 feet apart, with small ditches between the rows of trees. In some parts of Ceylon, Indonesia, Japan, and the Philippines, hillsides are terraced for cultivation. In Arabia, oil pipelines up to 3 feet in diameter are above ground for long distances. Long escarpments are found a few places on the Arabian Peninsula and on the Thailand-Indochina border. And over 1200 miles of the Chinese northern borders are still guarded by the ruins of the Great Wall, 12-16 feet high. The numerous irrigation features, canals, and dikes have been previously discussed. These may be significant obstacles to GEM operations in lowland areas, particularly during the nongrowing season, when the water level is low.

The diversity of Asia's physical geography generally limits overland GEM operations to the dry inland plateaus, the Arabian Desert area, and parts of the East China plain. Inland waterway operations would be advantageous in scattered areas of southeast Asia, and in parts of the Indian peninsula. Section 4 of this Chapter, dealing with amphibious and coastal operations, presents a more favorable picture regarding use of GEMs in Asia.

2. Africa

The military geography of Africa may be easily described in terms of desert and grassland plateaus, the equatorial forest belt, and the eastern highlands and rift valley. The climatic influences are very strong here, since topographic features are less pronounced than in other continents. Nonetheless, Africa presents a wide variety of terrain, drainage, and vegetation features. All of these have significant influence on military operations, and, in particular, on the natural environment for the operation of the Ground Effect Machine.

Much of Africa is a vast upland plateau, tilted slightly up toward the south and east. This plateau is mostly between 1000 and 5000 feet above sea level. The plateau is bordered by narrow east and west coastal lowlands, and a broader Mediterranean coastal lowland. In the northwest the Atlas Mountains rise in bold relief; and in the southeast, the plateau rises to 10,000 feet in the Drakensberg Mountains. The eastern edge of the plateau is marked by the spectacular rift valley, and extensive fault line extending from the Mediterranean to the Zambezi Gorge in Rhodesia.

This rift valley is bordered by the eastern highlands of Ethiopia, Kenya, and Tanganyika. The valley itself contains long steep-walled lakes, and is an effective barrier against east-west movement. In the south, the plateau terminates abruptly at the coast, with a steep escarpment. The island of Madagascar consists mostly of rough uplands, with steep eastern slopes, and partly scarped western slopes descending to a coastal plain.

The numerical data indicative of these topographic features are contained within Appendix B, and summarized in Table 5, as discussed in previous paragraphs. Although 5 per cent of the African land mass has an elevation of 5000 feet and above, this is predominantly in areas of steep slopes, which are "un-GEM-able" in any case. Only in the high plateau of Ethiopia exists relatively level terrain above 5000 feet elevation.

Areas of slopes over 30 per cent cover about 13 per cent of the continent. These areas ring the central plateau except in the north, and are predominant features in the eastern and southeast highlands and in Madagascar. Areas of 10-30 per cent slope are almost evenly distributed throughout the continent, covering 22 per cent of the area.

Drainage features in Africa are relatively less important to GEM operations than in other continents. Although most rivers are over 60 feet wide except in the mountains, falls and rapids are common at the edges of the central plateau, and steep banks are prevalent on nearly 75 per cent of the streams. In the arid north where most streams are intermittent, the wide wadies may sometimes be used as access routes, although banks are generally steep. Rivers of primary importance in Africa are the Nile, the Niger, the Congo, and the Zambezi. These are wide, but all except the Niger are obstructed by falls or dams, preventing their use for direct access from the coasts to the interior. For long stretches within the central plateau, these rivers may be used as access routes, but landing places must be checked for slope and vegetation coverage.

Swamps are common in the coastal region of the equatorial belt from Liberia to the Congo, and in smaller areas of the east coast. Swamps are also prevalent along the lower reaches of the Congo and the Niger, and make up a large portion of southern Sudan and central Uganda. The steep-walled lakes of the rift valley provide water routes along the Congo-Uganda-Tanganyika-Rhodesia

borders, but landing places are few, and the connecting streams are in narrow turbulent gorges.

Vegetation in Africa ranges from barren desert dunes in the Sahara to equatorial rain forests in French Equatorial Africa and the Congo. Dense forests cover 18 per cent of the total area, mostly in a belt extending from northern Congo westward through French Equatorial Africa, Ghana, and the new republics of the southern part of French West Africa. Some of these areas are accessible by wide rivers spaced 20-100 miles, but steep banks are common. Other large forested areas are in Tanganyika, Rhodesia, and Angola. Tropical savannah is a common African feature, with short (6 feet) and tall (15 feet) grasses, and scattered tall trees. In some areas, such as the eastern Congo and Uganda, elephant grass up to 15 feet high makes a rough entanglement, stopping most movement. Marshes in this region have reeds and papyrus 10-15 feet high, and clumps of floating vegetation up to 5 feet high.

The northern part of Africa is only sparsely covered by vegetation. In particular, the vast

Sahara Desert has only scattered brush, and large areas of barren sand plain and dunes. Although dunes and loose sand are not actually the most prevalent surface in desert areas, they account for 8 per cent of the total African land area. The large dunes of the Sahara have lee slopes from 30-60 per cent; some are as much as 800 feet high. These dunes are commonly aligned in north-south ridges, and may be circumvented (but sometimes by long detours).

Cultivated areas make up a very small percentage of Africa, and are primarily limited to the coast plain and the Nile Valley. The island of Madagascar is mostly covered with brush and grass.

The influence of all these features on cross-country military operations provides an index to the over-all military geography aspects. The cross-country capability of tanks and similar conventional tracked vehicles in Africa is about 75 per cent of the land mass area. (This includes areas where cross-country capability is quite poor, though possible.) The areas of unsuitability include the equatorial forest belt, the eastern highlands and rift valley, and the southern rim

highlands. The breakdown of areas unsuitable for cross-country operations in Africa, as summarized in Table 5, is: 12 per cent steep and rugged terrain, 6 per cent forested, 2 per cent soft and marshy areas, and 5 per cent for combinations of these features and others.

A few special features which have relevance for GEM operations have been included in the data assembled in Appendix B. There are scattered escarpments along the fringes of the Sahara Desert. The Nile Valley and coastal areas of Ethiopia are extensively dissected by irrigation ditches and canals up to 6 feet deep and 16 to 65 feet wide, with steep banks. These canals are empty in the low water season. There are some larger canals, and levee areas on the lower Nile, but banks of these are commonly not steep.

Other special features include the tough elephant grass and tall marsh vegetation, which have been previously discussed, and sand dunes, river gorges and falls. Cultural features affecting military operations are very sparse throughout Africa except on the coast and in the Nile Valley and Suez Canal areas. There are almost no railroads except in the Union of South Africa and along the Mediterranean coast. Most interior roads are

only trails and tracks across the desert and savannah.

In general, the geographic environment for GEM operations in the land mass of Africa can be summed up as broad usable areas separated by the forested equatorial belt, the rift valley and eastern highlands, and the southern highland rim. In addition, many areas in the south will have limited accessibility because of steep-walled river gorges. In the north, the effects of operation in the desert will be the primary environmental factor. The influence of all these factors and features on GEM practicability and basic design and performance parameters is further developed in Chapter II.

3. <u>South America</u>

The military geography of South America is dominated by the rugged Andes Range extending the length of the continent, and the dense rain forest of the vast Amazon Basin. These features have had a significant influence not only on military operations, but on economic development as well. The broad north-south spread of South America, from 12° North Latitude to 55° South Latitude, is another factor in the diverse physical geography of the continent.

The Andes Range stretches from the Caribbean to Cape Horn. Rising to 20,000 feet in Ecuador and Peru, it forms an effective barrier to east-west movement. Its high valleys and plateaus support human life only because of the more inhospitable nature of the humid rain forest to the east and the arid Pacific plain to the west. Slopes of the Andes are everywhere steep, and only a few high passes cross the range.

The broad Amazon Basin is one of the great wet forest regions of the world. The dense growth of tall evergreens and the humid climate prevent almost all military cross-country operations except those which can use the Amazon and its many tributaries as access routes. The Ground Effect Machine will have this capability.

Between the Amazon Basin and the Caribbean are tropical highlands and lowlands, mostly forested. East of the Amazon Basin are the Brazilian Highlands, descending abruptly to the South Atlantic. A great escarpment marks the border of the highland throughout much of southeast Brazil. Central southern South America consists of broad plains, with densely populated and developed areas in the Argentine Pampas. Further south, the plains rise and become heavily dissected in the "tableland" of Patagonia.

The continent continues even further south to the frigid hilly lands of Cape Horn, including a deeply fiorded coast of Chile beyond 40° South Latitude.

The numerical data contained in Appendix B and summarized in Table 5 indicate the primary features of the terrain bearing on military operations of Ground Effect Machines. South America has about 5 per cent of its land between 5,000 and 10,000 feet altitude and 5 per cent above 10,000 feet. But this high area lies almost entirely within the Andes, which, because of its ruggedness, is precluded from GEM operations of any kind. About 19 per cent of South America has slopes greater than 30 per cent, and 18 per cent has slopes of 10-30 per cent. The Andes Range, indicated on the climate zone map, Figure 4, as zone 23, is almost everywhere steeper than 30 per cent, and thus becomes an impassable barrier for east-west GEM operations of any kind. Other steep slope areas include the east rim of the Brazilian Highlands, and most of the rugged southern coastal areas.

Drainage features are important in South America. The broad Amazon and its tributaries form avenues of access to the central basin area. Numerous tributaries over 60 feet wide connect the

main channels which are usually well over 250 feet wide. However, the grassy and forested banks of the Amazon network are often steep and as much as 40 feet high. Other important river systems include the Paraná in Argentina and Paraguay, and the Orinoco in Venezuela and Colombia. The Andes are drained by numerous small swift-flowing streams, but these are rocky and filled with rapids and falls. Altogether, about two-thirds of the stream valleys in South America have steep banks.

Other drainage features include numerous swamps on the Caribbean coast and in the Amazon delta. Swamp areas surround the lower course of the Paraná in northeast Argentina and central Paraguay. The southern portion of the coast of Chile is cut by extensive fiords, very similar to those of Norway.

Vegetation is one of the most significant natural environment features of South American military geography. The continent is covered almost 40 per cent by dense forests, the largest forest coverage of any continent. Much of this forest is within the Amazon Basin, indicated as zone 4 in Figure 4. Most of the nonforested area is

grasslands, except in the Andes, where mountain scrub forest is common. Cultivated areas are relatively small, and concentrated mostly in central Argentina and surrounding areas. Desert sparse vegetation and barren areas cover the west coast from Peru through northern Chile, but actual sand dune areas are very small.

Cultural features are concentrated in very small areas of South America. These include the southern coastal region of Brazil and the north-east Argentina Pampas, which has the only dense rail network in South America. Other built-up areas are the central lowlands of Chile between the coast range and the Andes, and scattered areas of the Caribbean coastal plain in Venezuela. The rest of South America is almost devoid of cultural features affecting military operations.

Summation of the natural environment elements in terms of suitability for military cross-country operations indicates that about 60 per cent of South America is unsuited for such operations. Using tracked vehicles as the basis for evaluation, the primary cross-country obstacles are: dense forests - 30 per cent of total land area; steep and rugged areas - 20 per cent; wet and marshy

areas - 5 per cent; and combinations of forested and rough - 5 per cent.

Special features of the natural environment which are pertinent to overland GEM operations have been noted in Appendix B. These include the extensive fencing (up to 5 feet) of most railroads in the Pampas. In the Guianas, coastal cultivation is mostly irrigated. In the vast Amazon Basin, high humidity and precipitation levels may cause considerable damage to equipment which is not carefully maintained.

In general, South America is an area where GEM operations will be limited to coastal areas, the central and southern plains, and the numerous waterways of the Amazon Basin.

4. North America

The military geography of North America may be conveniently classified into three broad areas. Greenland and the northern-most islands of Canada are largely covered by ice, and exhibit all the characteristics of polar climate. The central North American area comprising Alaska, most of Canada, and the United States - a diverse region of highlands separated by a broad central lowland.

The southern region, from Mexico to Panama, and the West Indies, is a continuation of the highland region, with subtropical and tropical climates.

Greenland and the neighboring Canadian Arctic Islands -- Ellsmere, Devon, and the Sverdrup's -- are polar islands of barren rock and icecap, with only scattered low tundra and brush. Eighty per cent of Greenland is covered by the inland icecap, an empty ice and snow plain, crevassed and rough at its margins. The icecap lies between 5,000 and 10,000 feet above sea level. The barren coastal area of Greenland is almost entirely steep and rugged, and interrupted at 20-mile intervals by glaciers descending to the numerous fiords. The margin of the icecap is also cut by numerous rocky streams, and small lakes dot the coastal area. The Canadian Arctic Islands have similar features, with the east coasts rugged and fiorded, and the west coasts lower and less steep.

The broad central region of North America has a backbone of rugged mountains extending through southern Alaska, western Canada, and the western United States. In the U.S., the mountain backbone is spread out to contain high plateaus in the

north, and a desert region in the south. A second rugged mountain region occupies northern Alaska, enclosing the interior lowlands. These lowlands are carried across the Canadian northland, with tundra merging into a broad forest belt across the continent. A belt of less rugged uplands extends down the eastern side of Canada and the U.S., becoming separated from the Atlantic by a wide coastal plain in the southern U.S. A portion of these eastern highlands and plains is the industrial heartland of North America. The central lowlands of Canada and the U.S., predominantly grass covered or cultivated, are broad plains and low plateau, mostly level. The western highlands rise to 20,000 feet in Alaska (Mount McKinley), while the eastern highlands are mostly less than 6000 feet high. The large central lowlands are situated almost entirely at altitudes between sea level and 3000 feet.

The southern part of North America contains a continuation of the western highlands extending from Mexico to Panama. These highlands are arid and barren in Mexico, becoming wetter and forested further south. A narrow western coastal plain, and a wider eastern coastal plain, flank the

mountain ridge throughout the region. The West Indies are a chain of subtropical islands mostly with highland central cores except Cuba. These islands, extending from Florida to northern South America, form an arc across the Caribbean Sea.

On a continent-wide basis, the distribution of altitudes and terrain slopes in North America is given in Table 5. The altitude range includes 17 per cent from 5000 to 10,000 feet and 1 per cent above 10,000 feet. Most of this is in mountain regions, but large areas of the intermountain plateaus in the United States and Mexico are situated between 5 and 8000 feet. The breakdown of terrain slopes throughout North America is 48 per cent of total area with slopes less than 10 per cent; 27 per cent with slopes 10-30 per cent; and 25 per cent with slopes greater than 30 per cent.

There is a wide variety of drainage characteristics throughout the continent. The interior lowlands and eastern coastal plains of the United States and Canada are drained by a number of major rivers including the Missouri-Mississippi system. These rivers, spaced from 10-30 miles apart through

the lowlands, average 100 feet in width, and have steep banks in less than one-half of the area. In Canada, the rivers are replaced by numerous lakes, mostly greater than 5 miles long, and separated by less than 40 miles. In northern Canada and the central Alaskan lowlands the Yukon and Mackensie River systems provide access to a broad area, but are frozen 6 to 8 months each year.

With the exception of a few major rivers -- the Columbia and Colorado being two -- most of the stream valleys draining into the Pacific Ocean from the western highlands of North America are short and have steep banks. Their widths generally are from 60 to 250 feet. The rivers draining the eastern coastal areas of the southern North American countries mostly have steep banks, as do those of the West Indies. In the West Indies most of the rivers are from 60 to 120 feet wide, but some are less than 60 feet wide.

In addition to stream valleys, drainage features include swamps and marshes along the coasts from southern Mexico to Panama. Swamp and marsh areas are also common along the southeast coast of the United States. Subsurface karst

drainage is a feature of northern Florida, the Yucatan Peninsula in Mexico, and northern Guatemala, with few streams.

A prominent feature is the chain of Great Lakes between Canada and the United States, providing access to a large central area. Other large lakes are common in central and western Canada, but the connecting streams are swift and rocky. Parts of the Alaskan lowland and much of the northern Canadian lowlands are covered with poorly drained muskeg, which will support tracked and wheeled vehicles only when frozen.

There are a number of prominent waterways in North America including the Panama Canal (110 feet wide at the locks), the Soo Canal at Sault Ste. Marie on the Canadian-U.S. border, and the intracoastal waterway along the Atlantic coast of the U.S. Waterways in Canada, Alaska, and the U.S. are extensively used for commercial transportation throughout the lowland areas.

Vegetation in North America varies through the wide latitudinal range. Tundra in northern Canada merges with a wide forest belt, extending through part of the western United States. Other forests cover much of the eastern highlands region.

Dense forests reappear in the southern part of Mexico through to Panama. Altogether, about 32 per cent of North America is covered with dense forests. Brush and grass cover most of the interior lowlands and the islands of the West Indies. The western highlands and plateaus in Mexico and the southwestern United States are covered with sparse desert shrubs and grass, or are barren. Only a very small percentage of the arid lands is actually covered by sand dunes. Swamps and marshes cover about 3 per cent of the total area of North America, and an additional 3 per cent in the summer months when the muskeg is thawed. The central lowlands are extensively cultivated in grains. The eastern lowlands of southern North America and the West Indies are cultivated primarily with sugar cane, banana plantations, and coffee.

Cultural features are prominent in southeastern Canada, the eastern part of the United States, and in small areas in the central and western U.S. A dense network of roads and railroads also links these areas. Throughout the United States many fields are fenced by barbed wire to 4 feet high. Small a[illegible] through the entire region are irrigated, primarily in the Pacific Coast valleys of the U.S.

Military cross-country travel with conventional tracted vehicles can be carried out in about 45 per cent of the North American continent. Steep and rugged areas preclude cross-country operations in 25 per cent of the continent, mostly in the western highlands. Forested areas in Canada, the United States, and in the area from Mexico to Panama, make 20 per cent unsuitable. Wet and marshy areas stop movement in 2 per cent, and the icecap of Greenland and the Canadian Arctic covers 8 per cent.

All these features influence potential GEM operations in the region. Because of the densely built-up areas and transportation networks in much of the United States and southern Canada, GEMs would probably be most useful on inland waterways. The northern Canada tundra and muskeg area, and the Greenland icecap offer some advantage for GEM operations. Because of the rugged and forested terrain in the Caribbean area, GEMs would probably be practical only in coastal and amphibious operations, which are discussed in the next section. On a continent-wide basis, only a few areas in North America provide a natural environment advantageous to overland military operations of Ground Effect Machines.

5. Oceania (Australia, New Zealand and Pacific Island Areas)

Oceania, the smallest continental division, has a land area of just over 3 million square miles. Most of this is the island-continent of Australia. New Zealand and the Pacific Islands fill out the remainder. Although eastern New Guinea is politically part of Oceania, it has been found more convenient for purposes of this study to classify the whole island of New Guinea, and the adjoining Solomons, in Asia. The data appendices and summary tables reflect this classification.

Australia and New Zealand are islands of great contrast. Australia is a large arid plain and plateau partly fringed by wooded uplands, quite rugged in the southeast. Only a small percentage of the continent is elevated more than 3000 feet above sea level. Except in the southeast highlands and Tasmania, only 5 per cent of the slopes are over 30 per cent. Drainage characteristics include numerous small rivers in the coastal regions and on Tasmania, with a large central area of uncoordinated drainage. The rivers are spaced 20-50 miles apart, but in 75 per cent of the total area there are only a few intermittent streams. Banks of streams are not generally steep. A few marshes cover areas on the northern coast.

New Zealand exhibits much more rugged topography than that of Australia. A mountain backbone, rising to 12,000 feet, slopes unevenly down to a narrow coastal plain. About 50 per cent of the region has slopes greater than 30 per cent. Five per cent of New Zealand is above 5000 feet, but this is all in mountain areas. There are many stream valleys in New Zealand, separated by 5-20 miles, and with mean water widths of 60-250 feet. Most stream banks are steep. Fiords and finger lakes are common in the mountain region of South Island.

The remaining areas of Oceania consist of the thousands of Pacific Islands, only a few of which are large enough for consideration of overland operations. These islands may be coral, sand, or volcanic. Some, such as the Hawaiian Islands, have many steep slopes. Others are low and quite level. The volcanic islands have numerous narrow streams, which are not of any value as inland waterways.

Vegetation in Oceania ranges from dense forests in parts of New Zealand, the outlying islands and the fringes of Australia, to barren desert in most of the interior of Australia. Only 6 per cent of

the entire region is densely forested. About 18 per cent is covered by loose sand.

Cultural features affecting military geography are limited to the southern and southeast fringes of Australia, parts of New Zealand, and a few of the outlying islands. Most of central and western Australia has been quite untouched by cultural features.

Oceania is generally well suited for military cross-country operations. While much of New Zealand is rugged and forested, nearly 90 per cent of Australia is unobstructed for movement of tracked vehicles. Altogether, about 85 per cent of Oceania is considered suitable for cross-country operations.

The Ground Effect Machine could be used to advantage in much of Oceania, particularly where sparse vegetation and gradual slopes allow unimpeded operation at very low heights for long distances.

6. Antarctica

Antarctica is usually neglected in studies of world geography because of its inaccessibility and cold emptiness. With increased interest in exploring and studying this vast polar continent, and with the always present possibility of future military

operations in the area, a brief discussion of Antarctica in the present study is considered to be warranted.

Antarctica has a land area of about 5.5 million square miles, almost twice as large as Australia. Ninety-nine per cent of the continent is covered by ice. Perhaps 60 per cent of the total area is a continental glacier, mostly immobile, with an elevation of 6,000 to 12,000 feet. This continental glacier is bordered by a fringe of stream and valley glaciers which slowly descend to the abrupt coast. Small areas of the continent are barren rock breaking through the ice surface (nunataks) or forming rough borderlands at the sea coast. These rock areas are all steep and rough. Although much of the continent is unexplored, the probable altitude breakdown includes 40 per cent at altitudes of 5,000 to 10,000 feet, and 20 per cent above 10,000 feet. The continental glacier is fairly level, while the stream glaciers and valley glaciers are steep, rough, and much dissected by crevasses. Probably as much as 70 per cent of the area has surface slopes less than 10 per cent.

The glacier surface is covered with ice, or snow over ice (firn). Sastrugi (small ice ridges) up to 5 feet high and several hundred feet long are common in all areas. Crevasses are most prevalent at the edges of the continental glacier, but may occur anywhere. These crevasses may be up to several hundred feet wide and miles long. Pressure ridges around the rock outcroppings form major obstacles. Snow dunes on the icecap may be 40-50 feet deep and several hundred yards crest to crest.

Antarctica has almost no streams except small melt areas, which flood in the warm period. Drainage is through the slow action of the glaciers. There is no soil, (only rock) and no vegetation except mosses and lichens on exposed rock.

In terms of military operations, the bare ice areas can be crossed by wheeled and tracked vehicles with proper equipment for locating and bridging crevasses. On the snow cover, only light tracked vehicles may be used. The maximum bearing load on soft firn is about three pounds per square inch.

The Ground Effect Machine would appear to have limited capability for cross-country operations on

the Antarctic icecap. Auxiliary equipment must be installed to handle the problem of ingesting large quantities of loose snow. The large number of crevasses and rough areas at the borders of the icecap will probably severely limit any GEM operations in that area. Capability of the GEM in an area of crevasses has yet to be analyzed, but with proper detection equipment, it is believed that limited overland operations can be carried out in Antarctica.

4. COASTAL ENVIRONMENTS

(1) Classification of Natural Features

Improvements in marine technology, coupled with our world-wide economic and political interests, make the coastal environments of the world vitally important. Their significance to amphibious military operations is tremendous. The characteristics of the GEM appear particularly well-suited for operating within these environments.

The ability to surmount approach obstacles, such as sand bars and coral reefs; the high-speed performance (six-to-ten times that of present amphibians); and direct access inland from the sea without the water's-edge unloading operation, make GEMs an impressive vehicle for coastal and amphibious operations, whether military or commercial.

Generally, throughout the world, near-beach terrain offers obstructions such as forests, large sand dunes, coastal villages, escarpments, or a combination of these features. However, exits inland usually can be found by flanking these obstacles through use of river valleys, arroyos, cultivated areas, or natural depressions in the terrain. Rivers and streams offer excellent paths for GEM operations and can be used to advantage for penetration when some coasts are found to be otherwise impenetrable.

Sand dune and hill coastal areas make up a relatively small percentage of the shorelines of the earth. With respect to amphibious operations, this small percentage is extremely important for obvious reasons of accessibility, mobility, and defendability. However, the contours and possible obstructions of such areas are constantly changing (a) where strong seasonal winds can be expected to shift the sand, (b) where vegetation is sparse and the sand is easily moved, and (c) where waves or currents move abundant supplies of sand upon the shore or form bars or spits for additional deposits to build upon.

Normally the steepest angle of stability (from sliding) for dry sand is 30°. In such a condition of equilibrium any attempt to traverse the slope on foot or by vehicle disturbs the stability, and causes a sand-slide. Naturally, the higher the dune or hill, the more dangerous the condition. The steepest slope will usually be on the downwind side of the dunes which are at right angles to the prevailing wind. This type of coastal terrain is usually backed by marshes, tidal swamps, or periodically flooded ground. These are difficult obstacles to the inland movement of equipment and personnel using current facilities and techniques.

Delta plains are found on coasts that are intersected by sediment-carrying rivers which empty into

relatively quiet bodies of water. Such areas are usually fan-shaped, dissected by numerous stream interruptions, and offer exceedingly poor support for cross-country traffic. Such river mouths are a constant problem to navigation and must be continuously dredged and charted. This is expensive and may be an untenable condition in a combat area. Even shallow-draft, lightly loaded vessels are hampered under such conditions, but such a stream offers practically unobstructed routes for vehicles which could skim over the water or over the flat, sedimentary plain.

As the delta plain builds up from sediment deposits and the flood threat is eliminated, the area takes on increased commercial and military importance dependent upon the degree of ease a route to the interior can be obtained. Deltas in the tropics are usually fringed with swamps, cut by streams, and overgrown by tangled vegetation. The temperate zones support hardwood growth on the backing terrain while the colder zones support only low grasses and shrubs which give way to glacial cover farther north.

Coral formations are limited to the warm regions of the earth and are generally found between the 30° north and south parallels. The coral formations may be submerged or exposed. Generally, this depends on

the tidal characteristics in the region. Warm, protected, shallow approaches are excellent coral breeding grounds. Reefs are formed when the coral animal is exposed to the air and dies. The skeletons harden, forming reefs which are abrasive and hazardous. The Australasia (Oceania), Indian Ocean, and East African coastal areas represent the predominant areas of coral concentration in the world.

In addition to the generalized coastal land forms, other features of the coastal environments which are important to potential GEM operations are: vegetation, stream valleys, characteristics of beaches, surface-piercing obstructions in the offshore approach area, surf conditions, tides and currents, and climatic conditions. These features are discussed in this section on a world-wide basis. Application to GEM design and performance requirements is contained in Chapter II, Section 4. The detailed information presented in Appendix C was made compatible with already established climatic zones of the world as well as with political boundaries.

Tidal ranges, as presented in Appendix C, will vary through the years as well as during each year. Normal minimum and maximum tidal readings are presented because of the effect on operating conditions in any one region.

Surf conditions are not dependent upon tide alone, but also upon wind and other seasonal influences. A GEM must be able to withstand such an environment.

The gradient of a beach is of considerable interest in GEM design and is another factor which is included in the appendix data. The slope of the beach affects the performance and operational concepts to be considered in GEM planning. The gradient in the swash zone of the beach depends mainly on three variables; (a) the size of the beach material, (b) the length of the waves, and (c) the steepness ratio of the waves. More than half of the beaches reviewed in this study have gradients between two and three per cent in the swash zone between low tide and high tide. In the high-water zone, above normal tidal action, the slopes are somewhat steeper, averaging five to seven per cent. (The beach gradient, in per cent, is the tangent of the angle of the beach, i.e., the vertical rise per unit horizontal distance.)

Beach surface materials are also covered in Appendix C. Size of the beach material is not discussed because of its wide range, but the type of beach surface is given. Ninety per cent of the accessible coast are composed of sand, mud, pebbles, [illegible], or a combination of two or more of these. The remaining ten per cent

includes cobblestone, rock, seaweed, shingle, clay loam and debris.

In general, the coastal factors limiting GEM operations are those imposed by the shore terrain and not the near-shore or offshore approaches. GEMs can traverse most coral formations, submerged rocks, sand bars, and shoals. They cannot traverse shorelines made up of steep cliffs, bluffs and escarpments, nor penetrate beach jungles and nipa swamps, dense coastal settlements or other obstacles associated with civilization along a coast. Penetration usually can be made by bypassing such concentrations or by use of streams, rivers, or baylettes.

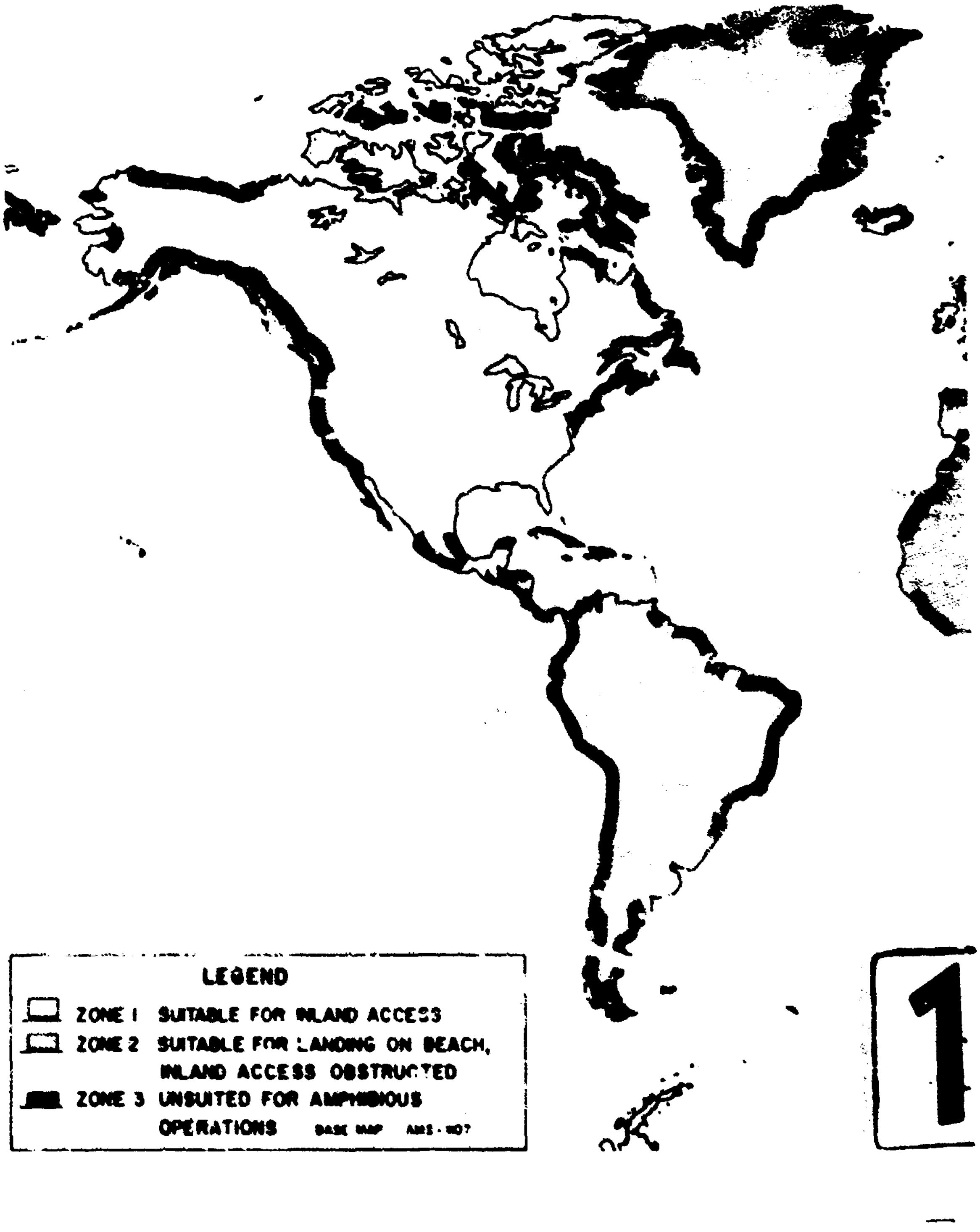
For military operations in a specific area, amphibious operational studies are available which provide the detailed data required for intelligent planning. In general, the coastal areas of the world where GEMs can be used are indicated [illegible] the map showing "Suitability for Amphibious GEM Operations" (Fig. 14).

The world coastline shown on this map is divided into three categories:

Code 1. Suitable for Inland Access.

Code 2. Suitable for Landing [illegible] Beach, Inland Access Obstructed.

Code 3. Unsuited for Amphibious Operations.


LEGEND
ZONE 1 SUITABLE FOR INLAND ACCESS
ZONE 2 SUITABLE FOR LANDING ON BEACH, INLAND ACCESS OBSTRUCTED
ZONE 3 UNSUITED FOR AMPHIBIOUS OPERATIONS
BASE MAP

1

2

FIGURE 14
Suitability for Amphibious GEM Operation

When Antarctica, Greenland and the remainder of the land mass north of the 77° parallel are excluded, it can be seen that approximately 70 per cent of the remaining coastline of the world is available for use with GEMs. At any one period during the year, winter icing conditions may alter this figure somewhat. Wet snow, blowing and drifted ice, and icebergs may present obstacles to the operation of some GEMs, but with provisions for deicing, and high-height, low-payload operations. all but the steep northern coasts will become accessible. Reference to Section 2 of this chapter will provide data to indicate seasonal problems which could nullify the Code 1 physical aspects of a coast and change it to an inaccessible area (Code 3) temporarily.

While the scope of the study requires some generalization of coastlines, predominant characteristics were used to determine operational suitability of the areas. More detailed analysis of a Code 1 coast, for example, may show numerous stretches of terrain which are impassable, and surrounding areas which may be suitable for cross-country inland movement.

Where coastal accessibility to inland terrain is indicated, individual coastal regions may present different problems. For instance, the region of northern Canada known as the Arctic Archipelago

generally consists of coastal plains which slope gently to the Arctic Ocean. Coastal backing terrain is made up of tundra with scattered low vegetation. Such features offer no obstruction to operations in the area. However, climatic features cause changes, such as hummocked ice, which must be taken into account when the details of operation in a specific area are to be considered. Consequently, the indications of accessibility for Africa would not have the same implication as for Alaska and other Arctic and Antarctic regions where surface features change with the seasons.

Tree-lined coasts often present barriers to inland access. However, such terrain is usually broken by river or stream valleys and there are often interruptions in vegetation which allow exits from the beaches.

Map scale limitations preclude a detailed indication of coastal conditions. The amount, type, and location of terrain which would support GEM operations usually determines the Code class. Several examples can be cited as follows:

Some parts of England and Northern Ireland are classed as Code 1 areas, while the remainder of the British Isles is a Code 2. While Wales and the territory south of Bristol Channel are composed of hills and mountainous terrain, the area is criss-crossed with

numerous navigable rivers which would offer no physical obstructions to GEM operations.

Similar considerations must be given to the southeast coast of the United States which is classed as Code 1. Deciduous forests, civilization and other natural and man-made obstacles would prevent even a GEM from moving directly inland from the shore. However, there are exits inland -- networks of coastal and interstate highways and numerous rivers. While river banks are lined with many trees, open spaces exist because of clearing for cultivation, timber harvesting, pleasure boating, etc.

The general impression of India is that of a teeming population cultivating flat plains and river bottoms with an ox and a crude wooden plow. This is only part of the picture. Most of India is made up of rugged terrain. It is traversed by many rivers and a well-developed rail network. These rivers and rail beds offer routes for GEM travel from the coastal regions toward the inland regions.

The East Indian coast is classed as Code 1. The West Coast is predominantly a Code 2 region since there are many places to support large landings, but the location and character of the western mountains are obstacles to inland movement.

A summary of the coastal environmental data, in terms of the GEM suitability code, is given in Table 6. For each major coastal division, the total coastline and mainland coastline lengths are given, as well as the percentage of total coastline in each code classification. Complete data on coastal environments are contained in Appendix C.

The following subsections discuss coastal features of the world's coastal areas except the rugged coast of Antarctica, which is ice bound throughout the year. This discussion is the background for the classification of amphibious Ground Effect Machines in Section 4 of Chapter II.

(2) Natural Features of World Coastal Areas

1. Europe

With the exception of Australia, Europe is the smallest of continents, but it has a total coastline of 40,000 miles (considering only minor indentations). This coastline is very irregular and encloses the continent on three sides as if it were a mammouth peninsula extending from the main body of Asia. Flat and gently undulating lands begin off the Strait of Gibraltar and follow the coast northward becoming gradually wider until they

TABLE 6

Summary of Coastal Environments

Continent	Ocean or Sea	Coast Length (mi.) Total	Coast Length (mi.) Mainland	Suitability for GEM Operations - % * Zone 1	Zone 2	Zone 3
Europe and Asia	Atlantic	29,525	17,225	40	41	19
	Baltic	6,991	4,386	88	12	-
	Arctic	21,310	15,460	73	12	15
	Pacific	27,913	26,250	9	78	13
	S. W. Pacific	39,600	4,320	14	36	50
	Indian & Arabian	12,490	11,550	27	23	50
	Eastern Mediterranean and Black Sea	6 739	6,338	38	62	-
	Mediterranean	11,950	7,035	21	62	17
Africa	Mediterranean	3,550	3,550	38	20	42
	Red Sea and Indian	9,915	9,590	46	32	22
	Atlantic	7,294	7,144	48	31	21
South America	Atlantic	10,900	10,650	34	62	4
	Pacific	9,210	5,780	-	30	70
North America	Pacific	12,645	9,755	13	68	19
	Arctic	42,350	33,400	16	17	67
	Atlantic	15,185	12,335	38	50	12
Oceania (Australia, New Zealand and S. W. Pacific Islands)		16,240	15,100	38	32	30
Antarctica		10,800	10,800	-	5	95
	World	285,607	210,666			

*Zone 1 - Suitable for Inland Access
Zone 2 - Suitable for Landing on Beach, Inland Access Obstructed
Zone 3 - Unsuited for Amphibious Operations

stretch from the foothills of Sweden to the Soviet Urals and south to the Caspian and Black Seas.

The entire coastline of European Russia within the Arctic Circle and 90 per cent of the Norwegian coast is composed of tundra or heath which impose serious restrictions on vehicular movement except when deeply frozen. The northwest coasts of the British Isles and the North Sea coast near Hamburg, Germany, are additional areas of widespread heath beds. Vegetation and civilization in these areas, except Hamburg, would offer no obstructions to amphibious operations.

Weather considerations along the coasts north of 57° North Latitude would require detailed study to determine ice and snow conditions before a winter operation could be planned. Rafted close pack-ice or close drift-ice, stacked up against even the flattest shore, could be sufficient to obstruct GEM operations. The effect of high-speed collisions with ice of this nature must be considered. New snow covering the ice or ground will make navigation difficult (a) because of being blown into the air by the jet downwash and (b) because of the crevasses or other discontinuities in terrain that it may camouflage.

In the Gulfs of Bothnia and Finland and the Baltic Sea, ferry traffic is restricted from around December 10 to May 20. Some years it is completely halted during January through March. Properly designed GEMs could negotiate this area and provide year-round access to these coasts, heretofore possible only with the airplane. A more complete discussion on ice, snow and other climatic influences is contained in section 2 of this chapter.

Sweden has many rivers and valleys which could be used for penetration from the coast. In addition, there are many interconnected lakes and bays that would serve as suitable access routes. Good beaches in the area are few in number. Beach surfaces consist of sand, silt and scattered rocks, with backing terrain of rocky and steep banks except in southern Norway and Sweden where the lowlands predominate. While Norway is 97 per cent mountainous, it has features providing access inland even though the size of the operation would be considerably limited by the width of the streams and the tributaries where one lake feeds to another. (Because of this limited-scale operational capability, a Code 2 classification was assigned to the Norwegian coasts instead of Code 1.) Stream and lake banks

are heavily wooded in most places and some feeder streams or canals are passable but obstructed by low bridges at scattered points.

The coasts of Scandinavia are clear in the Baltic and clear-to-channeled on the Atlantic. As can be expected along the Atlantic, the surf ranges from negligible to over 12 feet at times. Tides up to nine feet are experienced along the Atlantic coast, but are practically non-existent along the Baltic even though water level is changed up to six feet depending upon the strength and direction of seasonal and storm winds.

The Finnish, Russian, German, and Danish coasts along the Baltic Sea have lowland coastal terrain with characteristic climatic differences due to their geographical location. Rivers in the northwestern region are flooded in spring and early summer; during the winter they are frozen and navigation ceases. In the Finland-Poland area the predominantly sand beaches have an average slope of 3 per cent which gradually increases to around 6 per cent for portions of the Danish coasts. There are scattered islands obstructing offshore approaches, but the near-shore area is 85 per cent clear. The most common obstructions in the southern

end of the region, around Germany and Denmark, are shoals, sand and mud flats, and scattered rocks. Backing terrain generally is characterized by low-level sandy necks and meadow land with scattered trees, grass, and cultivated fields. There are only scattered areas of swamps and marshes, boulders, low cliffs and bluffs on the coasts. Tidal ranges are negligible toward the north but become appreciable (6-13 ft.) off the German North Sea coast. Surf through 70 per cent of the area from Finland to Germany ranges to 8 feet while the remainder of the coast rarely experiences surf over 5 feet in height.

The characteristics of the low and fertile 41-mile Belgium and 800-mile Netherlands coastal areas are well known. Except for scattered wrecks and shoals in the area, normal approaches are no problem. For GEM operations the wrecks and sea-walls represent the most formidable obstacles. Large drainage ditches in the area are 4 to 8 feet wide and up to 4 feet deep, but in places their banks are approximately level with the surrounding terrain, thus enabling GEMs to cross in these areas. Seawalls along the coast have steep (60 per cent) ramps at various intervals to

allow traffic to cross from one side of the wall to the other. The seawall is interrupted at several points by gates or lock-type doors which are closed during storms or high water but open for inland access at other times. Other backing terrain features are soft dry sand (firm when wet), sand dunes and cultivation.

Across the English Channel from the continent are the British Isles. The western portion of the islands are composed mainly of low hills; the east has areas of low plains, plateaus and rolling plains. The eastern coast of the main island is fairly regular; from the northern tip of Scotland to the southern tip of England there are only five big embayments. The southern coast has several protected harbors; the west is marked by indentations which run far inland and form many important commercial routes. Ireland has coasts just as rugged and indented as the west coast of the larger island.

Inland movement would be a minor problem for GEMs since inland waterways are plentiful. The Thames, for example, is navigable 47 miles from the sea; in Scotland the island can be crossed completely by following the Caledonian Canal from

the Firth of Lorne to Moray Firth in the north-east. Access can be made by numerous other waterways, but general cross-country travel by GEM would be difficult because of mountains in Scotland and southern Ireland.

Most of the beaches in the British Isles are gravel and loose cobble backed by firm wet sand (soft when dry) and scattered rocks; gradients range from 5 per cent to 10 per cent. Tidal ranges vary from negligible to 40 feet in the funnel-shaped bays.

The terrain around Calais, France, is similar to southeastern England. There are numerous beaches but they are backed by cliffs and seawalls ranging from 3 feet to 20 feet high depending on the tides and surf characteristics of the area. In this area where the Atlantic funnels into and out of the North Sea, the maximum tides approach 40 feet. Farther south in France and on the northern coast of Spain, the tidal ranges are considerably lower as the coast becomes more open along the Atlantic. However, while the tides are diminishing from 40 feet to 13 feet, the maximum surf heights remain about the same (up to 12 feet) but increase in frequency of occurrence during the

year -- predominantly during the winter storms.

The total coastline of France, including the Mediterranean coast, is 1,760 miles. The northwest (Channel) and the west (Atlantic Ocean) coasts are of a widely different physical and environmental character from the southeast (Mediterranean) coast. Nevertheless, both coasts are interrupted by accessible rivers and valleys, and have an abundant share of low, flat, and sandy coastal terrain bordered with dunes and marshes. But east of the Rhone Delta, the Alps and their offshoots extend to the sea. With these series of capes and rocky promontories, only a narrow "Riviera" remains between the heights and the shore. This is a characteristic feature found in all of the Mediterranean countries. Approaches to the shores on the Mediterranean side are mostly clear whereas approaches to the northern and western coasts are occasionally obstructed by bars, shoals and breakwaters. Tides and surf on the southern coasts are akin to the sunny disposition of the Riviera region and are classed as slight-to-moderate -- not over 5 feet.

The Spanish and Portuguese coasts are interrupted by six major rivers, all of which rise in Spain. By taking advantage of these rivers and their surrounding valleys easiest penetration to this sector of Europe can be obtained. The Guadalquivir River empties into the Gulf of Cadiz where broad sand deposits have formed a delta. These deposits have also cut off a large marshy lagoon, Las Marismas, which cannot be crossed by normal shipping or wheeled vehicles, but which provides a wide, flat expanse for GEM operations on a broad front.

Other lowlands are smaller and are restricted by surrounding hills and mountains. The Galicia in northwest Spain is made up of a succession of drowned river mouths which form excellent sheltered harbors for small craft. Such small harbors also offer concealment for amphibious operations and could be even more widely used by shallow -- or no-draft marine craft.

Tides up to 13 feet are found on the Atlantic side of Spain and Portugal while negligible recordings are found on the Mediterranean side. The offshore approaches to the beaches are generally clear and unobstructed. Beach slopes are generally

5-8 per cent. Most exits from the shore would be cross-country by paths and tracks through brush and seed cultivation to generally fair roads.

The remainder of the European Mediterranean coast is predominantly clear offshore with a few breakwaters and tidal flats fronting firm sand beaches in Italy and scattered rocks and reefs off the Yugoslav and Greek shores. Italy has numerous beaches with the terrain on the west side of the peninsula providing the best access routes inland. Streams are navigable inland from the coast for 20 to 30 miles; some rivers are navigable much further. In addition, there is a coastal canal that parallels the marshy coast of the Gulf of Venice, and another in the Po Basin which connects the cities of Turin and Milan. Because of sedimentation, the Po Basin is continually building out into the Adriatic as much as 300 feet per year. There are other canals which extend rivers and in most cases follow reasonably flat terrain, and could be used as GEM highway areas. The Tiber River is navigable as far as Perugia with shallow-draft vessels.

Coastal vegetation in Italy should not obstruct cross-country movement since it is predominantly

grass, brush, and cultivation with some areas given over to olive groves. The actual coastal terrain consists of marshes, lagoons, and dunes. A very small percentage of the total coastline has sea-walls, bluffs, and buildings which would form the only major obstructions. Tides and surf for Italy are consistent with the rest of the northern Mediterranean coasts.

The coastal plains of Yugoslavia and Greece are narrow and 50 per cent rocky with cliffs backing the beaches. Most rivers flow underground in Yugoslavia since the karst (limestone) formations are soluble, allowing the water to pass through. The four rivers in Yugoslavia which are important and accessible are bordered by cultivated low marshy lands. Inland from the coast, these usable rivers are cross-connected by canals which would obstruct GEM movement perpendicular to their courses.

The rivers of Greece are steep, rapid and unsuitable for navigation. Except for the upper part of Greece, there is no part of the country which is more than 40 miles from the sea. Frequent earthquakes, particularly on the southwest coasts, suggest that the land is still in a state of transformation. Constant reconnaissance in the area

is required to determine changes in offshore approaches and coastal terrain.

Surf in the area is high only when there are strong offshore winds. Usually it is negligible and is accompanied by tides of less than 2 feet. While there are many landing beaches in the Yugoslavia and Greece areas, the backing coastal terrain is rugged enough to make inland access by GEMs difficult. The beaches are of sand and gravel composition and the backing terrain is 70 per cent cliffy or mountainous. Roads, trails, and tracks can be found around ridges or up river valleys when available.

The European shores of the Black Sea are considerably different from those of the Greek Aegean Sea. The coastline is gently curving and regular until it reaches the Romania-Ukraine border where it is embayed and marshy. Ice restricts the shore approaches in the southern region occasionally, but in the north it is consistent in the winter. The hilly terrain in the south gives way to lagoons or steppes in the north around the delta plains of the Danube. Inland exits over tracks and trails through driftwood, scattered brush and cultivated plains warrant a Code 2 classification for much of

the Bulgarian coast. However, the low, flat, treeless area to the north in Romania would provide easy Code 1 GEM movement overland to the heart of the country.

2. Asia

Asia comprises about one-third of the earth's land area and is the home of nearly two-thirds of the population of the world. Asia lies wholly within the Northern Hemisphere and stretches over 5,000 miles from the Malay Peninsula in the south to Cape Chelyuskin within the Arctic Circle in northern Russia. Its east-west dimensions are approximately 7,000 miles. It is bounded on three sides by oceans and on the fourth by the Red, Mediterranean, Black, and Caspian Seas. The coast of over 100,000 miles represents a wide variety of types of shore.

The northern coasts are most notable for their ice-bound condition during the winter months; generally, these shores are low and deeply indented by the many rivers that flow from south to north to the Arctic Ocean. The Russian beaches are composed of sand, pebbles, and some boulders. Three-fourths of the beaches are over 100 feet wide with the remainder between 50-100 feet in width. The

backing terrain is mostly tundra plain and marsh with scattered bluffs and steep hills at irregular intervals along the coast. Vegetation in this region is low grass and moss with some scrub growth, none of which should provide obstacles to GEM operations.

Low winter temperatures, extreme isolation and short seasons when navigation is possible restricts settlement and interest in the area except for its strategic value. In the winter the many rivers are ice-bound and as they thaw upstream (in the south) before their more northerly lower reaches, great floods occur in the middle and lower basins each spring. In this region of Asia is approximately 10,500 miles of Code 1 coastline. Routes skirting patches of hummocked ice will be necessary in the winter, but once land is reached the GEM seems to provide the only year-round form of transportation. (In the winter the rivers are frozen and the snow is deep; in the spring the river basins are flooded; in the summer and the fall the marshes and tundra have thawed and the mire is deep.) Where there is surf, it is usually rough (5-8 ft. high).

In moving from the northern coasts to the eastern and southeastern Asian coasts, a dramatic change can be seen. The region is characterized by

numerous small and large islands, which were formed mostly by partly submerged volcanic folds. The coast from the Bering Strait to the Malay Peninsula is of a Code 2 classification with the exception of 15 per cent Code 1 and 3 per cent Code 3. This coast is much indented and broken by a series of seas and gulfs with pack ice occurring as far south as the Yellow Sea. Some of the greatest rivers in the world dissect the Pacific Coast of Asia. The flow of these rivers is generally at its maximum in the summer when the interior snows melt and rainfall is at its greatest. Near the coasts the rivers are gentle but they are restricted by levees and, somewhat like the Mississippi, flow above the level of the surrounding plains. Recurrent flooding hampers communication in the area and would eliminate travel by any conventional means during the period of flooding. Conditions are ideal for a craft with GEM qualities -- speed, flexibility and no restrictions with draft.

The best landing beaches are concentrated in the northeast portion of the Chinese coast but these are backed by villages, terraces and sea walls. The Grand Canal paralleling the coast from Tientsin to Hangchow offers another obstacle to inland movement by conventional vehicles but would be

surmountable at various points by GEMs with a jump capability of 4 to 5 feet. This canal is 30 feet wide and has the appearance of a large open drainage ditch over most of its length.

Southern China is rugged and intensely cultivated and populated. The coastal terrain is composed of a broad valley flanked by mountains and dissected by river valleys. There are few shore cliffs in the area but there are numerous villages and coastal roads. Most roads are poor and disconnected since river floods or monsoon rains wash out the roads and bridges as well.

Further south, Indochina lies wholly within the tropic zone. The southwestern monsoon combined with the heat supports dense tropical jungles and mangrove swamps often to the edge of the water. The immediate shore line is characterized by featureless deltas and swamps with some mountains to the sea in the northern region. The 1,700-mile coastline contains 119 major beaches which would support large-scale amphibious landings. Lateral communication lines with conventional land vehicles would be extremely difficult since most bridges cut during World War II either have not been rebuilt or are periodically destroyed by floods or current guerrilla warfare. It is difficult to travel more than 75

miles by road or rail before being stopped by a missing bridge or rail section. Most roads parallel the coast and may go inland 20 miles occasionally, but any travel further inland must negotiate dense jungle and rugged mountains. The best penetration can be made by numerous short waterways found in the area.

Approaches to the coast must pass islets, reefs, rocks, shoals, and some drying sand and mud flats with the tides ranging from one foot to 12 feet around Saigon on the southern tip. The surf in this area also approaches 12 feet at times. The beaches are predominantly wide at low tide and remain so at high tide except where tidal ranges are high. Eighty-seven of the 119 beaches are two miles or more long; they are 100 ft. or more wide; are made up of sand, mud and pebbles; have gradients of four per cent in the tidal wash zone and 10 per cent above the high water line. This average maximum gradient of 10 per cent is consistent throughout the southeast coast of Asia.

This region has excellent landing areas for GEM operations, but consideration of backing terrain, cultivation, vegetation, and population crowding the coast require that a "limited inland access"

(Code 2) classification be placed on the coast.

The next section of Asian coast covers some 3,800 miles around the Malay Peninsula and up the coast of Burma and East Pakistan. The many major beaches in this area are predominantly less than two miles long; composed of sand (soft when dry), mud and coral in places; have tidal ranges from 2 feet to 20 feet, and surf ranging from one-foot heights off the Cambodian coast to 20 feet near Rangoon. The offshore approaches include many islands, shoals and scattered rocks. The vegetation of the backing terrain is indicative of the climate in the area. There are dense mangrove stands, rain forests, palms, and dense secondary growth. There are swamps and mud lagoons, and few all-weather roads. Conventional landing conditions are best during the period from November through March. This would be extended where GEMs replaced conventional vehicles.

The island fringe of southeast Asia is an area of significant interest for GEM amphibious operations. From the weste.. tip of Sumatra to the eastern tip of New Guinea (a di..tance of about 3,200 miles) are two parallel chains of islands

with irregular coast lines, mountains, active volcanos, swamps, thick jungles, high temperature, high humidity and heavy rainfall. The islands were severely damaged during World War II and vegetation now present is comparatively new growth. Rubber and coconut trees are plentiful, and remaining growth, other than cultivation, is nipa swamps or rain forest.

The Sumatra coast is about 20 per cent Code 1, all of which is on the northeast side of the island; fifteen per cent is Code 2 which is scattered throughout the island; the remainder is essentially inaccessible for large scale landings. Java is 30 per cent Code 2; the remainder is Code 3. Borneo, including Sarawak, is 97 per cent accessible to GEMs. The most inaccessible area is its northern tip where a 13,455 foot mountain slopes to the sea.

The other large island in the group is New Guinea with Code 2 (15 per cent) scattered in equal amounts throughout the island. The remainder of the coast is Code 3 because of mountains extending to the sea, coral pinnacles on shore as well as offshore, and dense rain forests to the water's edge in most cases. The surf in the Code 1

southern region runs as high as 8 feet at times and the tide ranges from 2 to 17 feet depending on the season of the year. Beaches in the area vary from a width of 100 feet to some of 45 feet or less. Gradients range from one per cent in the south to nearly vertical in the west. In the east the beaches are predominantly steep with a six per cent to vertical gradient.

Most of the islands which are within ten degrees of the equator are mountainous, are fringed with nipa swamps or beach jungle, are ringed with coral formations, have moderate to very rough surf (3-12 feet), and have soft sand, soft mud or coral beaches. About 60 per cent of the landing beaches in the area are two miles or more in length and at low water 80 per cent are 100 feet or more wide. At high water, depending on the tides prevalent in the area and the beach gradients, approximately 50 per cent of the beaches are less than 50 feet wide with the remainder varying from 50 feet to 100 feet or more in width.

India and Western Pakistan, with 1,430 miles of coast line, have 140 major beaches. More than 80 per cent are over two miles long and 100 feet or more wide. The surf, depending on the season,

runs from 2 feet to 8 feet, and the tides range from 5 feet to 25 feet. The greatest tidal range is located just north of Bombay in the Gulf of Cambay, a region of extensive swamps, mud flats, and fishing stakes. Generally offshore approaches are clear except for scattered islets, rocks, shoals and bars. Beach gradients in South India average about 2 per cent while in northern India and Pakistan they run from flat to over 6 per cent. Exits from the beaches in the south are cross-country to coastal roads and railroads which are no more than 2 miles inland in most instances.

Most beaches are backed by swamps, marshes, and wasteland for several miles. Hills are jungle covered and dissected by many streams. Communications in the delta regions are almost nonexistent and the coasts are embayed with shallow approaches to the shore in these sectors. All rivers but the larger, more active ones are dry except in the rainy season. This does not exclude their use by GEMs as avenues of transportation when coastal jungles are impenetrable.

West of Pakistan and India are the coasts of Iran and Saudi Arabia. There are 5,000 miles of every type of coast from intensively cultivated

date groves through sand dunes and beach cusps to rocky hillocks 100 feet high. East of the Persian Gulf entrance and northwest of the Gulf of Aden the narrow coastal plain is backed by steep mountains rising to 8,000 ft. in places. In this region are mangrove forests, 200-300 foot cliffs in spots, and numerous streams fed from the mountains.

While one-half of the terrain is of this varied nature, the remainder is generally level, flanked by rocky promontories, low points of foul ground and scattered scrub on the beaches. The beaches in southeast Saudi Arabia are backed also by crusty, treacherous salt flats which are impassable during the wet season. In the Red Sea area beach exits are either nonexistent or unknown and the whole area is reported to be relatively unexplored. Inland movement would be cross-country to unpaved roads which at times may disappear or become impassable because of shifting sand.

The beaches are wide at low water, but with tidal ranges of up to 12 feet the widths are reduced to between 50 and 100 feet with high water. The sand, shell, and coral surfaces have 6 per cent or greater slopes in the eastern sector and tend toward slopes of less than 1 per cent in the west.

Beach approaches are restricted at the north and south ends of the Red Sea and where the Persian Gulf flows into the Arabian Sea. Otherwise, they are generally clear but shallow due to silting and coral formations.

The remaining coasts of Asia (Israel, Lebanon, and Turkey) represent a small portion of the over-all continent but at the same time are vital areas to the Western World because of their strategic location. The coast line becomes increasingly rugged in moving north from Israel to Turkey. In general, the seaward approaches are clear, but with scattered reefs, islets, shoals, and rocky ledges. While landing beaches are available, many man-made obstructions exist which would slow down amphibious operations. The most formidable of these are sea walls, piers, and oil pipelines offshore from storage tank farms. These obstacles combined with gravel or coral beaches of 3 to 10 per cent slope and a surf up to eight feet at times could make landing operations hazardous.

Inland movement of wheeled vehicles from the beaches on the coast of Israel is restricted to prepared routes because of sand dunes, sandstone ridges, cliffs, or bluffs backing the coastal

terrain. In Lebanon. mountains back the entire coast and cross-country travel is hindered by banks, rock outcrops, stone walls (3 to 4 feet high), hedgerows and dunes.

The portion of coast from Turkey through to the Black Sea is rugged with sand, pebble and cobble beaches. The western coast line of the Turkish Peninsula is probably the most accessible coast in this sector. It is cut into many bays and peninsulas with numerous offshore islands. Since central Turkey is a vast plateau rimmed by young folded mountains, its interior is not easily accessible. There are narrow plains between the mountains and the shore. Routes to the plateau would largely be up stream valleys. In the area of the Dardanelles and the Bosporus landings could be made, but it would be difficult for hostile forces to carry out military operations.

Surf in this area of the Mediterranean and Black Seas is rough (breakers to 8 ft.) even though the tides are negligible. Beach gradients are 6 to 10 per cent on the average for about half of the 341 beaches. The remainder are more gentle. About half are less than two miles long; about 80 per cent range in width from 30 feet to 100

feet; the remainder are 100 feet or more wide. The whole area is generally a Code 2 region.

3. Africa

The African shore line is generally undeveloped; it is heavily forested in the equatorial region and the coast of Mozambique and Tanganyika. This tropical rain forest gives way to light forest and grassland over the rest of Africa except in the desert regions of the north and southwest.

Because of its regular coastline, good natural harbors are scarce in Africa, and much of the coast is fringed with sand bars laid down by currents parallel with the shore. Along the equatorial regions of the coast, mangrove forests border the shores making the approach from the sea difficult. However, this area is classed as Code 2, since the beaches are cut by numerous streams which would allow some inland penetration for discharge of troops and supplies, and would provide concealment from air observation. Normal deep water ship operations are possible only on the Congo River. Others have delta deposits at the coasts which restrict river traffic to shallow draft or no-draft craft. Many have several navigable sections, but passage from one section to another is restricted because of rapids or waterfalls.

On the whole, the coastal plain is wider on the east coast than on the west. This is also the section of greatest tidal ranges (10 feet or more). The south and southeast coastal sectors cover all three GEM accessibility codes in a well-defined manner within less than 3,000 miles of South Africa and Mozambique. Rivers offer the main highways inland but many rapids are present and detailed study is required before operations can be planned with any reliability. At times of the year the Orange River, south of the Namib Desert, dries up; the rugged terrain surrounding this section of the coast precludes vehicular travel at any other point. Other rivers in the area are badly silted and must be dredged constantly to support any but the lightest traffic into a harbor or port.

In moving north up the east coast, the topography changes from land rising in terraces as it approaches the backing mountains to low, sandy areas with many swamps. This is also an area of heavy mangrove forests backing the shores. Where landings are possible, the sand and mud beaches have slopes ranging from 3 to 6 per cent. Roads and bridges are often washed out in the rainy season and the necessity of cross-country travel to reach tracks

and unsurfaced roads would present a problem for foot troops and wheeled or tracked vehicles during the rainy season. The coastal plain is 10 to 30 miles wide up through Tanganyika, but is backed by the steep central African plateau.

The plains flood readily during the season of heaviest rains between December and March and malaria and sleeping sickness are epidemic along the coast and up the Zambezi River Valley. Backing the mangrove lined coasts and below the mountains, the vegetation consists primarily of vast savanna. Many native villages line the coast, with extensive cultivation of sugar, cotton, timber, and coconuts in and near the many stream valleys.

The remainder of the east coast of Africa is rugged except the 1,200-mile coastline of Italian Somaliland. Here the beach gradient ranges from 2 per cent to over 6 per cent in places. The backing terrain is progressively steeper with low escarpment which is further backed by narrow sandy strips. The near terrain is unsuitable for wheeled vehicles because of dry, loose sand which shifts into high dunes. Scanty [illegible] and brush growth in the area would offer no obstruction to inland movement. Extensive irrigation is practiced in

the vicinity of the two main rivers (Scebeli and Juba) in the area. Most exits from beaches are cross-country to coastal trails and very poor roads.

The sides of the Red Sea are rugged and difficult for amphibious landings because of the mountainous terrain sloping to the sea. The area between this coast and the Nile River is almost entirely uninhabited except in the fertile Nile Valley. The Nile is navigable for over 800 miles and provides easy Code 1 access to the region. The flood season begins in July and lasts into October.

Except for the Mediterranean coast and the Nile Valley, the northern part of Africa is arid, sandy and supports little vegetation. There are many coastal roads paralleling the coast from Algeria to Egypt with fair cross-country access from the beaches. In Tunisia, cross-country access is occasionally impeded by large dunes and some lagoons.

Surf on the Mediterranean coast varies from a maximum of 3 feet in some areas to 8 feet in others, with beach gradients running from 1 per cent in the western regions to nearly vertical where the

Atlas Mountains in Algeria meet the sea. Within this 3,800 mile region to the Gibraltar Straits there are 284 major landing beaches. Thirty per cent of these are partly obstructed by reefs, coral and sand bars up to five miles from shore.

Around the horn of the western tip of Africa, Morocco has a largely impenetrable coast because of the extension of the mountains in this region. However, there are several fairly large rivers in the area by which access can be obtained to the interior of the country. These rivers are unnavigable for ocean vessels because of sand banks blocking their mouths. The surf in the area ranges up to 13 feet and the 3 to 6 per cent gradient beaches are of firm sand (soft when dry). Approaches from the Atlantic are somewhat obstructed by reefs, rocks, bars, wrecks, and fish nets. Scattered on-shore obstructions consist of low wave scarp and 10 to 30 foot sand ridges and bluffs. Tidal ranges between 8° and 13° North Latitude are the greatest anywhere along the west African Coast. In addition to the equatorial jungles in the lower region of the coastal bulge there are large rubber plantations with trees spaced 20 feet apart. There is a wide variety of beaches in this section of the sand and mud coast. There are flat

beaches and there are those with slopes to 10 per cent; there are beaches less than 50 feet wide and there are those over 100 feet wide; there are those with clear offshore approaches and there are those (in Nigeria and the Cameroons) with scattered shoals and wrecks. The most consistent feature of the area is the obstruction of near-shore approaches by shoals, sand bars at river entrances and scattered rocks, wrecks and reefs. Ninety per cent of the beach exits are cross-country to coastal tracks and trails which in turn lead to unsurfaced roads.

While the coastal plains are more narrow than those on the east coast they have many of the same characteristics -- low lying, swampy, sand beaches backed by marshes or lagoons, undulating backing terrain to the mountains. The entire area is dissected by numerous rivers and streams. Except in the arid regions of the Sahara and Namib Deserts, the entire coast is backed by forests of varying density -- decreasing in proportion to their distance from the equator.

There are few good natural harbors, and sea swells which increase considerably in the south add to the problem of shifting sand deposits, completely closing off rivers and ports if dredging

is not employed. More and more jetties are being constructed to halt the movement of the sand, but this merely shifts the bar further from the beach, where the build-up starts to close the entrance all over again.

4. South America

South America and Africa both are cut by the equator and consequently both have hot, moist jungles. While South America is less than two-thirds the size of Africa, it has a much greater quantity and broader area of rainfall than Africa. This moisture is concentrated in the northern half of the continent, setting the pattern for the dense growth of vegetation. From the mouth of the San Francisco River, near Recife, down the coast to the southern tip of Brazil are heavy coastal vegetation growths. An isolated coastal stand of heavy growth is found in the vicinity of Valparaiso and Concepcion in Chile. The main coastal forest region begins in Ecuador and follows the coast northward, crossing the isthmus, then eastward past the mouth of the Amazon River. Inland, the trees attain great height, forming such a dense canopy that the forest floor is sparsely vegetated except where light can penetrate. On the coast the trees are low and stunted, and it is difficult to distinguish between trees and shrubs.

The greatest density of South America's population is found on the southeast coast of the continent. The center of this concentration is the metropolitan area of Buenos Aires. This large city is located on the Paraná River Delta at the southern entrance to the great Central lowland. This is an area with great grasslands similar to that found in the prairies of North America. There are well-developed forests along the streams and grasses on the steppes which cover the southern end of the lowlands. The beaches in this area are not recommended for conventional amphibious operations because of their flatness and lack of concealment. There are many bluffs backing the beaches but continued inland movement is possible by using the stream beds which dissect the coast in many places. About 500 miles south of Buenos Aires the region is arid, and vegetation and population are sparse. Once access to this territory is attained there would be no problem in progressing northward up the backbone of the continent.

In addition to the Paraná River basin there are two other large, almost continuous lowlands associated with rivers on the Atlantic Coast -- the Orinoco and the Amazon. The Brazilian Amazonia,

the lowland bordering the Amazon River and its tributaries, makes up about a third of Brazil and includes all of the northern portions. The entire region is one of great uniformity and exhibits only slight relief. Fifty per cent of the area is below 500-feet elevation. In the vicinity of the rivers much of the region is swampy and often flooded during periods of high water.

The coastal plain of Brazil is fairly wide in the north as it merges with the Amazonian lowlands and reaches its greatest width at Bahia where it averages about 50 miles wide. From there southward it becomes extremely narrow and is rarely more than a few miles wide in southern Brazil. Even though Brazil has almost 5,000 miles of coastline it has few good natural harbors. In the north and south the low lying, marshy coasts backed by lagoons have not been developed because of the threat of flooding and the problem of building up the land to support settlement. The eastern coasts are straight and high, offering little protection for harbors.

The shores are composed of sand which is firm when wet. Slopes range from less than one per cent to greater than six per cent. The approaches

offshore are generally clear except for scattered shoals extending for some distance offshore in the north and reefs, rocks, shoals and sand bars in the southern region. Tidal ranges of over 20 feet can be found in the vicinity of the Amazon River, but generally throughout the rest of the coast tides are 2-6 feet.

While landings can be made all up and down the coast, only in the vicinity of the lowlands of the Paraná, Amazon, and Orinoco would the operation be simplified. In the lowlands where flooding has occurred, the banks are tapered. Further upstream where the rivers are narrow and the flow is swifter, the banks are eroded at the top, leaving steep ridges. In all cases, except where the influence of civilization has been felt, the banks are lined with trees. Where the climate is hot and humid, there is dense undergrowth along the banks in areas where the sun penetrates the shade.

Exits from Atlantic coast beaches by trails to fair-to-good roads in the Salvador-San Paulo area of Brazil. Further south, the roads are not as good. Roads in Argentina especially, are incapable of withstanding sustained military traffic.

The northern part of the continent beyond the Amazon basin is generally a Code 2 area except where the lowlands of the Orinoco basin influence the terrain. The area has some mud flats and clay but is composed predominantly of sand. The foreshore gradient ranges up to 20 per cent in places on the coast of Surinam but drops to around 5 per cent in the backshore area. The Caribbean coast beaches range from an 8 per cent slope to less than 1 per cent.

Offshore approaches require caution for shipping in the area north to Colombia because of foul ground, scattered rocks, reefs, bars and islets. On the nearshore approach oil-well derricks, pipe lines, piers and jetties are a hazard when coupled with 8-foot surf found in the area during storms. The backing terrain consists of lagoons, barrier islands, marsh forest stream valleys and some quicksand. The area consists of three types of coastal terrain: (a) steep and rocky with narrow sandy shores, (b) low to hilly with some sand shores and some bluffs and cliffs, (c) low, flat swamp with muddy or sandy shores.

In the coastal area around the isthmus of Panama, movement inland is difficult if not impossible

because of the mountains backing the shores and the dense tropical forest covering their slopes down to the sea The Pacific coast of Colombia has one of the highest rainfalls in the world and the area is very humid.

Rivers on this coast are short and swift, unsuitable for travel by GEM. Most are rocky with many rapids along their courses. Sixty per cent of the surrounding area is unsuitable for GEM operations. The remainder is Code 2 type of territory with steep terrain backing the shores.

Along the shores of Colombia and Ecuador, the surf runs above 10 feet at times and the tides range from 4 to 13 feet. Tides at the southern tip of Chile in the Chonos Archipelago range as high as 20 feet in places and the surf is violent (15 feet or more) along the whole southwest coast during winter and spring.

Most of the roads on the coast are poor, and not connected. They must be supplemented by trails, waterways and railways. Because of the mountainous terrain and the high cost of highways, the most frequently used routes are narrow trails suitable for pack animals. In Chile, coastal roads are nearly nonexistent. Domestic and international

aviation is well developed to combat the difficult problems of communication imposed by the terrain. The Code 2 classification for the coastal area surrounding Concepción, Chile, is a borderline classification. Landings could be made, but penetration of the coast beyond the beach with GEMs would be in the stream valley areas only and would be extremely limited.

5. North America

As in South America, the western coasts of the continent are the most rugged. It is almost a single great chain of mountains beginning in Alaska and extending southward through Canada, the United States, and Central America. In Central America, highlands extend almost without a break throughout the length of the narrow body of land. The only extensive area of level land occurs in the Yucatan Peninsula of Mexico. Elsewhere, plains and lowlands are few.

The coastal plains are narrow along the Pacific and slightly wider on the Caribbean side. The coast is deeply indented and irregular. The coasts of the Gulf of Mexico and the Caribbean are marked by large bays and lagoons. The offshore approaches on both sides of the isthmus are generally clear

with scattered islands and extensive coral formations obstructing the near-shore approaches. As the line of greatest elevation is generally nearer the Pacific than the Caribbean, the rivers draining to the west are short and swift flowing. Dense tropical rain forest occurs on the wetter lowlands with mangrove predominating on the coasts.

Exits inland from beaches in Central America are poor and in most cases consist of tracks leading to urban areas. Highways are well-developed only around large cities. Large sections of the area are without roads suitable [illegible] vehicular traffic and [illegible] do exist are impassable in wet weath[illegible]. A[illegible]r and water traffic are both important in Central America largely as a result of the inadeq[illegible]ate and primi[illegible]ive land transporta-tion. Rivers and lakes fo[illegible] important route[illegible] and coastal n[illegible]igation is [illegible]en used.

There are many beach[illegible] suitable for landing in the Central America ar[illegible]. They range from 25 feet to over 1[illegible] feet wi[illegible] and about half are two or more miles l[illegible]g. San[illegible] is the general beach material and it [illegible]s firm [illegible]hen wet. Gradients on the Atlantic sid[illegible] are 4 [illegible] cent to [illegible]early horizontal while on [illegible]e Pac[illegible]ic side they run from 1 per cent to about 3 pe[illegible] cent.

On the Pacific side off the coast of Guatemala, the tides are the highest in the area and often run over 10 feet. On the Atlantic side of Guatemala (and British Honduras) the surf is the highest -- up to 12 feet at times. Approaches to the shores are partly obstructed by barrier reefs, shell ridges, coral heads and sand bars on both oceans. Backing the beaches are some low scarps, dunes, mangrove forests and swamps.

The Mexican coastline totals about 5,470 miles, with 1,710 miles on the east and 3,760 on the west. In addition to the continental portion, Mexico includes the two large peninsulas of Lower California on the Pacific side and Yucatan on the Gulf of Mexico side. The Lower California section extends southward from the main continent about 760 miles, paralleling the Mexican mainland. It is rugged with numerous landing beaches but with few vehicular exits from the beaches. This area ranges from one to seven miles inland and is backed by mountains with steep-sided valleys and one or more of the following: ridges, scarps, strips of sand, dunes, hills, intermittent streams and lagoons. Tides in the horseshoe area in the northern part of the Gulf of California run as high as 20 feet with the remainder of the coast tapering to as low as 3-foot

tides. Surf in the upper Gulf is very mild (one to two feet) while in the less protected waters it runs as high as 8 feet, depending on the season and weather.

Gradients on the peninsula as well as the mainland range from 2 per cent to around 9 per cent with predominantly sand beaches. The approaches from the west are clear on the peninsula but the approaches to the mainland are channelized and obstructed by rocks, reefs, islets, and shoals. The mainland backing terrain is similar to that on the peninsula but not as rugged, with easier exits by tracks to coastal roads and railroads. At the southern end of Mexico there is a narrow plain across the Isthmus of Tehuantepec which extends to the east coast. In other sectors of the west coast there are more narrow corridors or lowlands which extend to the interior from most beaches.

On the east coast the Yucatan Peninsula extends to the northward about 280 miles into the Gulf of Mexico. It is an area of low-lying marshy land with few lakes or rivers. While not as extensive as on the peninsula, there are lowlands throughout the whole eastern coast. They extend some 30-miles inland and form a tropical belt which is heavily forested. The coast is deeply indented with bays

and gulfs. There are many large islands off t
coast.

Because of shallow lagoons, silted river ths,
and shallow water, there are no natural harbor 1
the east coast. (The west coast, in contrast,
has some of the finest natural harbors in the ld --
Acapulco being an example.) There are five ri s
on the Atlantic side which are navigable for s
distance from their mouths. A constant check
kept on the delta depths to assure that siltin
does not close the channels. The surf is gene ly
rough (5-8 feet) but tides are mild, ranging
between 1 and 3 feet during the year. The san nd
shell beaches have about a 4 per cent slope in a
tidal wash zone, up to about 7 per cent in the ne
above high tide.

Cuba and other islands of the West Indies ve
about the same coastal features as eastern Mex .
They are broken, sandy shore lines with numero
bays, inlets, coves, and lagoons. Island inte 's
are usually heavily wooded with heavily cultiv l,
sloping plains to the sea. There are many bro
rivers in Cuba but only one of commercial impo nce.

The Atlantic and Gulf Coastal Plains of t
United States stretch from Cape Cod to Florida

and along the Gulf of Mexico. The area is generally low-lying and cut by many streams. is deeply indented and marked by coastal lagoo tidal marshes, deltas, and spits. The inner b dary of the Atlantic Plain is the fall line of the er Appalachian Highland and the Gulf Coastal Plai extends north to the interior highlands and ce al lowland.

The eastern coast is generally level and marked by a 10-mile-wide coastal belt of swamp land in the southern two-thirds of the country Bordering the coast is a series of low sea isl s built by silt from the rivers and separated fr the mainland by inlets and salt-water rivers w h form the greater part of an inland waterway pa - leling the coast. The central coast rises abo 3 feet per mile from sea level to about 300 fe in the vicinity of Washington, D. C. The surf of the beaches is predominantly sand in the so and gradually becomes more rocky on the northe coasts of Maine.

The northern Atlantic coasts of North Ame a are rocky with some salt marshes and narrow, s p beaches. There are spate bars, offshore isl s and numerous wash crevasses, coastal settlemen

streams, and evergreen forests. Tides a
coast range from 9 feet to over 30 feet
Hudson Bay area. The surf along the Nor
is over eight feet during the winter sto

The Gulf of St. Lawrence is particu
cluttered with islands and restricted ch
The beaches in that region are composed
mud, as well as cobblestones. The wide
valleys of Nova Scotia, New Brunswick an
Lawrence region are highly populated, an
cations routes are highly concentrated i
east sector. The coastal terrain in sou
is steep and tree-lined with a submerged
and marsh area near the Bay of Fundy T
Labrador is steep and rocky and densely
The Hudson Bay area has a lowland belt o
backing the shore which is icebound most
year. Almost 50 per cent of Canada drai
Hudson Bay and the many stream valleys i
even though rocky, offer reasonable acce
inland areas by OFMs from the bay.

The island area within the Arctic C
Archipelago) embraces a vast triangular
of islands which are part of the coastal
sloping gently to the Arctic Ocean. The

streams, and evergreen forests. Tides along this coast range from 9 feet to over 30 feet in the Hudson Bay area. The surf along the North Atlantic is over eight feet during the winter storm season.

The Gulf of St. Lawrence is particularly cluttered with islands and restricted channels. The beaches in that region are composed of silt and mud, as well as cobblestones. The wide cultivated valleys of Nova Scotia, New Brunswick and the St. Lawrence region are highly populated, and communications routes are highly concentrated in the southeast sector. The coastal terrain in southern Canada is steep and tree-lined with a submerged forest and marsh area near the Bay of Fundy. The coast of Labrador is steep and rocky and densely forested. The Hudson Bay area has a lowland belt of trees backing the shore which is icebound most of the year. Almost 50 per cent of Canada drains into Hudson Bay and the many stream valleys in the area, even though rocky, offer reasonable access to the inland areas by GEMs from the bay.

The island area within the Arctic Circle (Arctic Archipelago) embraces a vast triangular shaped group of islands which are part of the coastal plains sloping gently to the Arctic Ocean. The area is ice

bound much of the year but the general terrain should offer no obstacles to inland access in many areas. The only vegetation in the area is of the tundra dwarf-tree type. The Mackenzie River Valley offers an easy route inland especially during the cold, frozen season.

West of the Mackenzie River are the Richardson Mountains, blending into the Brooks Range in Alaska. This is extremely rugged territory with the north coast of Alaska following the frozen pattern of northern Canada. During the thawing season, overland travel is practically impossible by conventional means. The coastal backing terrain is fairly level but the area is covered with innumerable lakes. The area is usually completely isolated because of the formidable range of mountains. Air travel is the only feasible mode eight months of the year.

Further westward and southward around the coast is more of the same rugged terrain. In placee the mountains extend to the sea and in others the sand, pebble and cobble beaches are backed by lagoons and intersected by streams. The constant freezing and thawing makes the area unsuitable for any wheeled vehicles larger than a jeep. The very irregular shoreline has limited exits along gullies or between lagoons to the tundra farther inland. Most beaches

are backed by bluffs. Only tracked vehicles could be used for medium heavy-duty operations on land heretofore. GEMs will offer significant advancement in this area in the future. Offshore approaches are cluttered with scattered shoals, rocks and islets south and east of the Alaskan Peninsula. North of this area the sea approach is generally clear. The islands and peninsula are crossed with many streams on their relatively level northern side, but on the Pacific side all shores are steep and rugged right to the sea.

The Yukon River provides the shores along the Bering Sea with a Code 1 classification because of its access route to the interior. Farther south, Cook Inlet provides a protected area for landings, but the primary exit inland through the surrounding mountains is by the Alaska Railroad.

Farther south along the coast is the highest and most rugged portion of Canada. This region includes the offshore islands and the Coast and St. Elias Mountains in the most westerly sector. The coast line is penetrated by many fiords with steep shores and backing terrain. Among the numerous islands fronting the shore are the large Vancouver Island and the Queen Charlotte group, all

of which are a part of the complex which forms comparatively restricted and channelized approaches to the mainland. The only place of any size on the coast lower than 1000 feet is at the mouth of the Fraser River at Vancouver, B.C. Landings that could be accomplished in the area would be restricted in size and inland access by heavy woods and rugged terrain.

The west coast of the United States is a continuation of the features found on the Canadian coast, but the density of ruggedness decreases toward the south. Forests of pine and fir mantle much of the area with wide belts of redwood along the coast in the south. Puget Sound area is the lowest coastal area in the north. It offers waterway penetration for about 100 miles east plus its southward branches--Admiralty Inlet and Hood Canal (60 miles). The surrounding shores are densely forested.

The coastal ranges paralleling the shores of the northern area are interrupted by several valleys. The shores are predominantly rocky and steep slopes form the backing terrain. Rivers and river valleys offer the best _ 'and routes,

e.g., the Columbia River is navigable with small ships for about 460 miles. Besides the wide mouth of the Columbia, there are several small bays and harbors. There are many beaches in the area and several coastal parks. Exits inland are by scattered roads, tracks, and cross-country to many coastal highways which parallel the shores.

In general, the coastal plain is extremely narrow but widens out somewhat in the south. San Francisco and Monterey bays are the only major indentations in the southern section with the former providing one of the world's greatest natural harbors. In other regions the beaches are backed by rocky cliffs, bluffs, wooded areas, or densely settled regions. While offshore approaches for GEMs would be generally clear, continued inland movement would best be accomplished by wheeled vehicles except where rivers and suitable adjacent valleys are available.

6. Australia, New Zealand, and Pacific Islands Areas (Oceania)

Oceania was most effectively brought to world attention during World War II. It was this area that really tested triphibious (amphibious) strategy, capability, and flexibility.

Many wrecks still remaining in the area resulted from grounding on shoals or severe damage inflicted by coral reefs and not from enemy action. The 1250 mile coral reef guarding the northeast coast of Australia has long been a hazard to marine navigation in that area. At high tide the reef is submerged; at low tide it is partially exposed. A GEM capable of operating two feet off the surface should have no problem crossing the area. Surf in the area is strong and during severe storms damage to the bottom of GEM could result in pitching were a problem and the craft "grounded" on the coral while moving forward at high speeds.

In the extreme northeastern section of Queensland Province, even after crossing the barrier reef successfully, a landing would be difficult in the region around Musgrave and Cooktown. This area contains the extreme northern tip of the Great Dividing Range which extends to the sea. On either side of this area is a Code 2 region where landings may be made, but inland movement by GEM would be impossible with today's development. This region is rugged and tropical rain forest vegetation covers the area.

The southern coasts of Australia are characterized by rugged cliffs, many bays and inlets, and good natural harbors. Eastern Australia and Tasmania have coasts of rocky headlands and bays with some wide sandy beaches. Southeastern Queensland, eastern New South Wales and Victoria are the most populated areas in Australia. The southern end of the Great Dividing Range extends into the Great Valley of Victoria. The coastal region of New South Wales and Victoria supports a thick growth of Eucalyptus trees, some of which grow 300 feet or more high. The combination of topography, population, and vegetation causes this region to be classed as unsuitable for amphibious GEM operations in the region between Sandy Cape and Sydney and limited-suitable (Code 2) in the surrounding area.

The northern coasts are low and level around the shallow Gulf of Carpentaria, but farther west they become very indented as the land rises higher, shores become cliffy, and coral reefs reappear off the coast at Cape Londonderry. The surrounding area, eastward from Queens Channel in Northern Territory and westward from [illegible] Sound at Derby, Western Australia, will allow penetration inland through the shores or through rivers and estuaries.

The west coast is more regular and the north-moving offshore current creates numerous large sandbars which protect the coast from the south and west. The highest tides in Australia are prevalent in this region ranging from 3 feet up to 31 feet. From West Cape Howe in the south to Cape Londonderry in the north the vegetation is varied and follows the general pattern expected in the climate characteristic of the area. Eucalyptus and woodland growth around Perth in the south give way to mallee scrub and mulga savannah in the arid central coast and temperate mixed forest in the extreme northern area.

New Zealand, with a coastline of 3000 miles and tidal range of 5 feet to 15 feet is a land of many faces. The rocky coast is generally straight with few good natural harbors. The shores are bordered by extensive beds of sand and shingle which continually block river mouths and harbors. The islands are 18 per cent forested. This is predominantly on the west coast of the south island and the center of the north island. The two main islands are extremely mountainous but are cut by rivers and "U"-shaped valleys which provide access to the area at the extreme northern tip and the extreme southern tip of the islands.

The remainder of Oceania represents a relatively small part of the over-all land-mass of the sector, but its significance in world-wide politics must not be overlooked or underestimated. It extends north as far as the Hawaiian Group and west as far as New Guinea and the Carolines.

In the Hawaiian Islands, for example, GEMs would offer rapid inter-island transportation to augment air travel and supplement marine travel but inland use would be severely restricted. The islands are mostly mountainous with cliffy headlands in the northern parts of most islands. Fifty per cent of the islands have rugged coasts with sheer, impassable cliffs and deep rivers, while the other 50 per cent are composed of white beaches and marginal lowlands. The islands are made up of five volcanic mountains and are one of the few areas in the world that are still in the process of formation. Island approaches are generally clear for this reason--even though the water and temperature conditions are ideal for large coral formations.

II. CLASSIFICATION OF MILITARY GROUND EFFECT MACHINES

1. INTRODUCTION

The world-wide environmental data summarized in Chapter I may be used as a basis for classifying military Ground Effect Machines into families by size and operating height. The distinction between marine, amphibious, and overland operations is retained during this classification, although a certain amount of overlapping may easily be anticipated.

The approach to vehicle classification on the basis of the operational environment is perhaps unique. Such an approach, however, seems more appropriate than optimization of vehicle parameters and then searching for potential applications. The development of GEM classes within this chapter is carried out within the broadest boundaries of "practical" GEM designs. The classification itself puts very specific limits on how big the GEM can be and what it must do. The tabulation of vehicles in Tables 11, 13 and 15 is, in effect, an envelope of basic vehicle requirements within the three categories of anticipated operation. The following ground rules, outlined in the Introduction to Chapter I, should be kept in mind:

(1) The development of the GEM classification considers only vehicles for transport of personnel and cargo. Special purpose vehicles are not included.

(2) No significant breakthroughs in the present state-of-the-art have been assumed, although improvements in component and system efficiencies are included.

2. DISCUSSION AND CLASSIFICATION OF MILITARY GROUND EFFECT MACHINES - MARINE

Climatic and oceanographic data for the ocean areas of the world are summarized in Chapter I, Section 2. These data form the basis for a classification of marine Ground Effect Machines. Table 7 shows the environmental factors having most specific influence on marine GEM operations.

(1) Wave Height

For the majority of marine operations, the wave height in the operating area will be the most significant environmental factor present. Wave height determines the minimum GEM operating height. At high forward speeds, the vehicle will not be able to follow the wave system without exceeding human and structural acceleration limits. For the same reasons, it should not hit any wave crests. Experience to date on model and prototype GEM vehicles indicates that an operating height equal to one-half the wave height (trough to crest), is adequate for cruise operation without hitting wave crests.

Wave heights throughout the ocean areas of the world have pronounced seasonal variation. Figures 10 and 12

Table 7
Environmental Factors in Marine Operations

Environmental Factor	Influence
1. Wave height	Operating height, area and seasonal limitations.
2. Sea ice	Operating height, area and seasonal limitations.
3. Wind	Control power design speeds.
4. Temperature	Powerplant output, superstructure icing - Chapter III.
5. Salt spray	Design and equipment requirements - Chapter IV.
6. Other climatic factors 7. Induced environment factors 8. Combat environment factors	Design and equipment requirements - Chapters III, IV.

in Chapter I, following page 85, show the frequencies of five-and 12-foot waves over the oceans of the world, during the local winter season and the local summer season. Table 8 summarizes these data.

From the tabulated wave-height data, a range of seasonal operating feasibility can be developed for the major ocean areas of the world, divided into latitude bands. These results are tabulated in Table 9. The data in Table 9 provide a sound basis for classification of marine Ground Effect Machines, with operating height as the primary parameter.

(2) Sea Ice

The occurrence and height of solid and floating sea ice has a significant effect on the operations of marine GEMs. Figures 8 and 12 in Chapter I, following page 85, summarizes the occurrence of sea ice in the winter and summer hemispheres. Reference to these figures and the accompanying discussion shows that these areas are limited to above 60° N in the winter and above 80° N in the summer, in the North Atlantic Ocean; while in the North Pacific the occurrence of sea ice is very uncommon even during the winter. In the southern hemisphere, the ice pack around the Antarctic continent extends to 65° S in the Pacific, and 56° S in the Atlantic in the winter,

Table 8
Summary of Wave Height Data
(See Figures 10 and 12, Chapter I)

		Percentage Occurrence of Waves			
		Summer		Winter	
Ocean	Latitude	> 5 ft.	>12 ft.	>5 ft.	>12 ft.
North Atlantic	0-20° N	10-30	neg (5)	10-50	< 5
	20-40° N	5-30	neg	20-70	neg-20
	40-60° N	20-50	neg-10	40-80	10-50
North Pacific	0-20° N	<10	neg	neg-30	neg
	20-40° N	neg-10	neg-5	10-80	neg-30
	40-60° N	neg-20	neg-5	10-80	10-30
South Atlantic	0-20° S	<20	neg	neg-30	neg
	20-40° S	10-40	neg-10	neg-60	neg
	40-60° S	30-60	10-40	20-80	neg-20
South Pacific	0-20° S	<20	neg	neg-30	neg
	20-40° S	10-50	neg-10	10-50	neg-10
	40-60° S	40-80	neg-70	30-70	10-40
Indian	0-20° N	neg-50	neg-10	< 10	neg
	0-20° S	neg-20	neg	neg-60	neg
	20-40° S	10-40	neg	10-60	neg-10
	40-60° S	20-60	5-40	20-60	neg-20
Arctic	Above 60° N *	neg-40	neg-20	10-50	5-40
Antarctic	Above 60° S *	20-70	neg-60	10-50	neg-30

*Partially ice covered - See Figure 8

Table 9
Seasonal Operating Feasibility - Ocean Areas

Percentage of Time Operations are Feasible at Given Heights					
		Summer		Winter	
GEM Operating Height (ft)		2.5	6	2.5	6
Ocean	Latitude				
North Atlantic	0° - 20° N	60-90	95	50-90	95+
	20° - 40° N	70-95	95	30-80	80-95
	40° - 60° N	50-70	90-95	20-60	50-90
North Pacific	0° - 20° N	90+	95+	70-90+	95
	20° - 40° N	90-95	95+	20-90	70-95
	40° - 60° N	80-95	95+	20-90	70-90
South Atlantic	0° - 20° S	80+	95	70-90+	95
	20° - 40° S	60-90	90-95	40-90+	95
	40° - 60° S	40-70	60-90	20-80	80-95
South Pacific	0° - 20° S	80+	95	70-90+	95
	20° - 40° S	50-90	90-95	50-90	90-95
	40° - 60° S	20-60	30-95	30-70	60-90
Indian	0° - 20° N	50-95	90-95+	90+	95
	0° - 20° S	80-95	95	60-90+	95
	20° - 40° S	60-90	95	40-90	90-95
	40° - 60° S	40-90	60-95	40-60	80-95
Arctic	Above 60° N	60-95	90-95	50-90	60-95
Antarctic	Above 60° S	30-80	40-95	50-90	70-95

while receding to near the continental limits in the summer.

Very little quantitative data about thickness of ice and surface roughness are presently available but, for example, ice hummocks 20-25 feet high occur in the Arctic Ocean, north of the U.S.S.R. The fringes of the ice pack are likely to have rough surfaces and large floating fragments, and should be avoided for most GEM operations. Since ocean-going GEMs will probably have to be equipped with radar for collision avoidance, operation in areas of infrequent icebergs should not be particularly hazardous.

(3) Wind

Winds are more significant in marine GEM operations than in overland and amphibious operations. This is a result of the higher occurrence of prevailing surface winds over water areas than over land, as well as the necessity to provide fuel reserves for longer-range operations.

Since the GEM operates as a free air vehicle (except vehicles with sidewalls), the effect of wind is similar to that on aircraft. Ground speeds are reduced by headwinds and increased by tailwinds. Components of wind

normal to the flight path require control power for crabbing the vehicle into the wind.

Wind data for the ocean areas of the world have been summarized in Chapter I, Figures 9 and 11, following page 85. These maps show the percentage occurrence of surface winds above 10 knots and above 33 knots (gale force). The wind data distribution is similar to those for wave heights, since wave height is largely a function of wind. Accordingly, the requirements for operation in frequent high winds usually accompanies the requirement for operation in frequent high waves. Table 10 summarizing occurrence of winds above 10 knots and above 33 knots may be matched closely with Table 8 showing occurrence of specified wave heights. The data of Table 10 may be used to further specify the basic parameters for marine GEM vehicles in terms of control power requirements and in terms of design speeds required to achieve a given point-to-point speed.

For operation in coastal waters only, the requirements for traversing wave systems are often greatly reduced. While wave heights will be a less severe limitation; ice, wind, surf, and width of channels will determine the feasibility and requirements for GEM operations. Further analysis of such operations is contained in the next section of this chapter.

Table 10

Summary of Wind Data

(See Figures 9 and 1[illegible], Chapter I)

		Percentage Occurrence of Winds			
		Summer		Winter	
Ocean	Latitude	>10 kts	>33 kts	>10 kts	>33 kts
North Atlantic	0° - 20° N	10-60	<3	30-60	<5
	20° - 40° N	10-60	<3	30-80	neg-15
	40° - 60° N	20-60	neg-5	60-90	10-30
North Pacific	0° - 20° N	10-60	<5	40-60	<5
	20° - 40° N	10-60	<5	40-70	5-15
	40° - 60° N	10-50	neg-5	60-80	5-[illegible]0
South Atlantic	0° - 20° S	20-50	<5	20-60	<5
	20° - 40° S	20-70	neg-5	40-80	neg-15
	40° - 60° S	60-80	5-15	60-90	5-20
South Pacific	0° - 20° S	10-60	<5	30-60	<5
	20° - 40° S	10-60	neg-5	40-70	neg-10
	40° - 60° S	50-80	5-15	60-90	5-20
Indian	0° - 20° N	40-70	neg-15	10-50	<5
	0° - 20° S	10-60	<5	20-60	<5
	20° - 40° S	40-70	neg-5	60-80	neg-10
	40° - 60° S	50-80	5-15	60-90	10-20
Arctic	Above 60° N	30-80	neg-10	60-90	15-30
Antarctic	Above 60° S	No Data - - - -	- - -	No Data - - - - - - -	

The suggested classification of marine GEMs is given in Table 11. There are two broad groups of vehicles classified in this table. Classes I to V are marine GEMS with conventional annular jet or plenum chamber systems. Classes I-A to V-A are marine sidewall GEMs with solid portions of the vehicle extending below the water surface, in the most typical case along the longitudinal dimensions only.

The sidewall GEM has been shown to have lower power requirements at low speeds. Its high-speed capability is, however, severely limited by wave drag. The sidewall GEM is also precluded from all operations outside water areas, except by very special design and construction. For overwater use the stability afforded by surface contact may in some cases outweigh the speed and operating area limitations imposed on the sidewall configurations. The effects of operations in wave systems on sidewall configurations are being investigated. Until further test results are available, it is considered appropriate to classify these with the same size full GEM configurations.

The classification of marine GEMs outlined in Table 11 is based on planform sizes and operating heights appropriate for over-water operations. The corresponding sidewall configurations listed in the right columns of Table 11 are intended for use on water surfaces only, while the "full GEM"

Table 11
Marine GEM Classification

						Sidewall Configurations		
Class	Size (Feet)	Normal Cruise Height (Feet)	Max. Cruise Height (1/2-2/3 Cruise Speed) (Feet)	Seasonal Feasibility	Design Wind for Operations (Knots)	Class	Base Clearance Height (Feet)	Seasonal Feasibility
I.	20 x 40	1	1.5	Choose operating area in Table of Summary Wave Height Data and match normal and max. cruise heights.	15	I-A	1.5	Choose operating area in Table of Summary Wave Height Data and match base clearance height.
II.	[illegible] x 60	1.5	2.5		20	II-A	2.5	
III.	50 x [illegible]0	2.5	4		30	III-A	4	
IV.	75 x 150	4	6		30	IV-A	6	
V.	1[illegible]0 x 200	6	10		40	V-A	10	

(full peripheral jet or curtain) configurations may have limited operating capability in cleared land areas adjacent to waterways.

For each marine vehicle class the normal cruise height is the operating height above the undisturbed water surface for the design cruise speed. Because of the depression of the water surface by the air cushion at hover and at low speeds, the design height for determination of power requirements will be somewhat greater, particularly for high planform loading GEMs.

The maximum cruise height is the operating height at cruise power for operating over wave systems at speeds from one-half to two-thirds of normal cruise speed. The maximum cruise height for marine GEMs has been chosen as approximately 50 per cent above the normal cruise height. Analysis of power requirements for current state-of-the-art GEMs shows that this height can be maintained at about the same over-all cruise power, if the speed is reduced to one-half to two-thirds of normal cruise speed.

With the operating condition of the vehicle height equal to half of the wave height, the seasonal operating feasibility in the open sea can be roughly determined by reference to Table 9. Inspection of Figures 10 and 11 will, however, give a somewhat better geographic picture of operating feasibility in a given area.

The warning previously given about application of these results should be kept in mind: planning a specific operation or route requires the application of data more detailed than that presented in this chapter.

The design winds listed in Table 11 are the maximum winds likely to be encountered at least 10 per cent of the time in the areas with wave heights matching the maximum operating heights specified for each class. Control power and propulsion power for each class of vehicle should be sufficient to provide the desired performance in all winds up to the value given. Alternately, a vehicle specification should indicate acceptable performance degradation in the presence of these winds.

Pending the outcome of current laboratory investigations, the sidewall configurations are classified on the basis of base clearance heights (measured from the bottom of the vehicle, not including the sidewalls or skegs) equal to the maximum cruise heights of the full GEM configurations. When more data become available on structural loads and stability of the sidewall configurations in wave systems, the classification may be modified if necessary.

Effects of temperature, salt spray, and other climatic factors, as well as those of the induced and combat environments, are discussed in Chapter III. A [illegible] discussion of vehicle performance within the classification of Table 11 is

presented in Chapter IV. This includes the development of power requirements and payload-range capabilities.

A parameter of particular importance in marine operations is vehicle cruising range. It is perhaps obvious that the smaller vehicles cannot operate freely in ocean areas, even during the calmer periods, because their range is limited by the available fuel load. Some further discussion of fuel consumption and range determination is included in Chapter IV.

From the environmental point of view desirable ranges for marine GEMs are a few miles -- for travel from a mainland to offshore islands -- to transoceanic stage lengths upwards of 2,500 nautical miles. Because of the great variety of areas in which military (or commercial) marine GEMs may be operated, two examples of typical numbers in the range problem may be useful.

Assume marine GEM operations are being carried out on a general network of routes in two areas: the Mediterranean Sea and the Southeast Asia island fringe. What ranges would be appropriate for these operations? By neglecting, for the moment, all other considerations, some typical range numbers can be obtained.

The Mediterranean Sea is about 200 miles long, but mostly less than 350 miles wide (all distances in nautical

miles). Overwater distances between pairs of terminals, grouped in convenient stage lengths, are listed below:

100 miles: Venice-Trieste, Beirut-Cyprus, Malta-Sicily, Sicily-Tunisia, Tangier-Gibraltar, Nice-Corsica.

100-200 miles: Rome-Sardinia, Marseilles-Corsica, Athens-Crete, Tripoli-Malta, Palermo-Naples, Algiers-Coast of Spain.

200-300 miles: Rome-Marseilles, Algiers-Barcelona, Alexandria-Coast of Turkey, Athens-Coast of Libya, Bizerte-Naples.

300-500 miles: Algiers-Marseilles, Algiers-Gibraltar, Barcelona-Rome, Alexandria-Athens, Palermo-Genoa, Tunis-Genoa.

Marine GEM operations in Southeast Asia would connect a number of islands with each other and with the mainland. A representative area would include Indonesia, the Philippines, Taiwan, the coastal area of China, Indochina, Thailand, Burma, and the Malay Peninsula. Distances between islands within the Philippine group averages less than 50 miles, while in Indonesia the range is 50-200 miles. Distance between island groups in this area and the mainland varies from 100 to 600

miles. Some representative overwater distances within this area are given below (all in nautical miles):

Hong Kong-Taiwan	330
Hong Kong-Philippines (Lingayen Gulf)	500
Saigon-Singapore	590
Saigon-Borneo	620
Singapore-Djakarta	480
Taiwan-Amoy	130
Borneo-Manila	560
Java-Borneo	260

The two examples above are representative of some of the areas of the world with numerous overwater routes. Military planners will be able to adapt the range data presented in Chapter IV to the particular area of interest. For the present, range requirements will not be specified within the marine GEM classification

3. DISCUSSION AND CLASSIFICATION OF MILITARY GROUND EFFECT MACHINES - OVERLAND

The world-wide environmental data for overland operation of Ground Effect Machines are summarized in Chapter I, section 3. The background data are contained within Appendix B. Based on the available state-of-the-art data (29, 32, 37, 39) for GEM design and performance, Table 12 shows specific influences of each factor on the basic vehicle parameters.

Table 12

Environmental Factors in Overland Operations

Environmental Factor	Influence
1. Altitude, temperature, humidity	Power plant performance
2. Slope of surface terrain	Power requirements, area limitations
3. Drainage features	Vehicle size, area limitations, speed limitations
4. Vegetation and surface cover	Operating heights, vehicle size, area limitations
5. Terrain obstructions and discontinuities	Operating heights, power requirements, speed limitations
6. Wind	Control power
7. Sand and dust	Downwash control - Chapter III
8. Other climatic factors 9. Induced environment factors 10. Combat environment factors	Design and equipment requirements - Chapters III, IV

These factors are discussed in some detail in the following paragraphs.

(1) Altitude, Temperature, and Humidity

These factors influence primarily the powerplant output. Data covering the range of operating altitudes have been assembled as part of the physical features and are listed below.

The world-wide breakdown of altitudes of all land areas is as follows:

below sea level	negligible
sea level - 3,000 feet	70%
3,000 - 5,000 feet	19%
5,000 - 10,000 feet	8%
over 10,000 feet	3%

Because most of the higher elevation areas are associated with areas of steep slope, they are ruled out for GEM operations anyway. Based on world wide operations, the appropriate distribution for over and GEM operations should be more nearly:

sea level - 3,000 feet	90%
sea level - 5,000 feet	99%

From these numb- -- can be see- that provisi-. f- high altitude ope- -ns will not be a serious prob- -em if present-day ai-c- and automotiv- vehicle type power plants are use-.

(2) Slope of Surface Terrain

The basic principle o- the -round effect machi- allows power requirements to be -gnificantly -d f- those required to lift the ve- -cle in f-ee air. When -EM operates on a -ting s-face, th- -ight component p- -el to the sur-ace must be balanced by direct thrust, - unaid- by the ground effect, or by surface friction. Th- -versing areas of steep slopes requir- uneconomical -nts of pow-r.

The dis-ribution of terrai- slope- -ghout the world is as follows:

slope gradient	0 - 10%	58% of la- -ea
	10 - 30%	23% of lan- area
	greater than -0%	19% of land -rea

(sl-es expressed in per cent gradient should be dis-inguished from angles ex-ressed in degrees: -- gradient is the tangent o- the angle.)

-vision of power for opera- -n in areas of slope gr- -. than 30% (where direct thru- must equal .30 x

gross weight to hold position) is uneconomical for present state-of-the-art machines. Since these areas are for the most part segregated in the mountainous areas of the earth, they will be considered "un-GEM-able" and eliminated from further consideration for GEM operations throughout this study. Local areas of steep slope must be avoided during operations. Short, steep slopes on the banks of rivers, gullies, and other terrain depressions are discussed later.

Slopes of .0 per cent to 30 per cent will also require additional power expenditure for operations. However, these areas are widespread and quite evenly distributed throughout the world's land masses. It is, therefore, necessary that ground effect machines designed for overland operations should have at least nominal performance capability [illegible] perhaps 5 mph speed is sufficient in areas of [illegible] up to [illegible] per cent. Even a GEM design only for [illegible]ted local operations will need slope capability up to about 15 per cent.

g. [illegible] requirement to be applied to overland GEMs for [illegible] effect machines is then:

li[illegible]ed local operations, slope capabili[illegible]

[illegible] cent

for general overland operations, slope ca bility to 10 per cent at normal operating speed, and slope capability to 30 per cen nominal speed <u>in all directions</u> (the GEM be controllable on downhill runs and side slopes, as well as uphill climbing).

(3) Drainage Features

The ability of the ground effect machine to ut waterways for cross-country operation is a signific feature ... thinking toward military applications. overland GEM should be able to operate ... along ... across stream valleys; thus the ability to climb st banks is important. Many areas of the world are ac sible only through waterways; and the high-speed ca bility of the GEM in these areas will add to milita unit mobility.

The characteristics of stream valleys and othe land waterways peculiar to each continental area ha been discussed in Chapter 1. On a world-wide basis widths of the majority of inland stream valleys at mean water level is between 60 and 250 feet. Altho the reliability of a specific number is poor, it is estimated that about three-fourths of the streams military significance are over 100 feet wide, and

95 per cent are over 60 feet wide. In the ... most of central Africa, European U.S.S.R., ... China, India, and parts of Alaska and Asiat... most of the rivers are over 250 feet wide. ... the rest of the world are a number of wide ... viding access to large areas; many of the tr... of these rivers are, however, less than 250

Experience of the British with the Hove... SR-N1 indicates that GEMs can be operated ef... only where the width of the river is three t... that of the vehicle. In closer quarters, wh... problems are more critical, the GEM could s... operated as a displacement vessel.

GEM vehicles with sidewalls extending b... water surface may also be used to advantage ... Since these craft cannot operate in land are... classified with the marine GEMs.

In addition to the stream valleys, ther... ber of artificial waterways in many of the ... of the world. These range in width mostly f... 150 feet, but many narrow to 30 feet at brid... waterways will probably be of only limited u... operations because of the width restrictions

Operation on frozen waterways is als
Under these conditions obstructions of fl
hummocked ice can be treated as any other
structions.

Most inland waterways, whether natur
cial, generally have calm surfaces so tha
height of one foot will be sufficient. A
in use of waterways is access from the ad
areas. In most of the mountain areas of
streams have high steep banks which limit
places. Throughout the world only about
the stream valleys have generally free ac
to water and back, so that operations may
planning.

Use of stream valleys for GEM operat
impose a restriction on cruising speeds b
high control power needed to traverse sma
bends. With GEM design state-of-the-art
level, lateral accelerations of .1 to .15
maximum which can be obtained. Using the
..., turning maneuvers of small radius
out at relatively low speeds only. For e
.1g lateral acceleration, a 90° turn at 4
require a radius of 1,420 feet; at 30 kno

of turn would be 800 feet; at 60 knots it would be 3,200 feet.

The curvature of rivers varies greatly from place to place, but measurements from several large scale maps indicates a range of commonly encountered characteristics. For large rivers with widths of 300 to 1,500 feet, bends of radius 1.5 to 6 x width occur at spacings ranging from 8 to 30 x width. For the majority of rivers throughout the world, which are between 100 and 250 feet wide, as noted earlier, application of these parameters indicates that operations of small GEM vehicles on waterways with widths of 100 feet will probably be limited to cruising speeds below 30 knots, and operations on waterways with widths of 250 feet will probably be limited to about 40 knots.

Higher speeds could be used on straight stretches, although acceleration and deceleration will consume part of these distances. For example, with typical GEM acceleration and deceleration capabilities of .1g and -.2g, respectively; the distance to accelerate from 40 knots to 80 knots, and later to decelerate to 40 knots again, is nearly 3,200 feet. This is almost half the longest straight stretch between bends on typical rivers of 250 foot width.

The significant result is that operations on most inland waterways will only occasionally be able to utilize speeds in excess of 400 knots. Thus, specification of design cruise speed for overland GEMs in excess of 600 knots is probably not warranted. GEMs with sidewalls will have less severe maneuvering problems, but their speeds are limited by wave drag.

The significant results of considering stream valley and inland waterway operations for GEMs throughout the world are:

1. 200-foot width vehicle width usable with ease on 99 per cent of streams,

   300-foot width vehicle usable on about 75 per cent of streams,

   500-600-foot width vehicle usable in large areas of central South America and central Africa, western U.S.S.R., southern China, India, and scattered locations elsewhere (e.g., Mississippi-Missouri system, Yukon, Nile but blocked by dams in south), and Tigris-Euphrates;

2. steep banks are prevalent in all mountain areas, and generally on about two-thirds of all major

streams. The banks will permit access to and from rivers at limited points only. Power requirements for climbing river banks are discussed in the paragraph on terrain discontinuities;

3. average speeds on inland waterways will be limited to 40 knots for the majority of operations.

(4) Vegetation and Surface Cover

The many varieties of vegetation and other surface cover provide obstacles and hindrance to the passage of ground effect machines as well as other vehicles. The degree of hindrance is closely related to the height, spacing, and stiffness of vegetation.

The environmental data of Chapter I summarize prominent vegetation types by continental areas, and Appendix B includes these data on a detailed geographic unit basis. The most significant vegetation element on a world-wide basis is the extent of dense forests, which cannot be traversed by GEMs without extensive clearing operations. These forest areas cover about 24 per cent of the world's land surface.

It has been proposed in several GEM analyses that GEMways could be cleared in forested areas without the expense of drainage provisions, surface compaction, or paving. Within the world's dense forest areas, even this approach to developing a transportation system would require use of heavy equipment over an extended period of time. Thus, cleared GEMways in dense forest areas will probably be utilized only for anticipated long-term or permanent operations.

At present, consideration of GEM operation in forest areas should generally be limited to waterways and cleared roads, railroad rights-of-way and pipeline areas. The latter cleared areas are generally rather narrow, s as to hinder free passage of GEMs with widths greater than 20 feet.

Forms of vegatative cover other than dense forests are considered to offer passage for GEMs to a greater or lesser degree. Sparse brush and widely scattered trees are considered to offer very little hindrance to GEM operations. In contrast, dense low brush cannot be penetrated and must be overflown. Grass areas and fields of grain will not be a significant hindrance, even when tall, as in parts of East Africa. But the tough elephant grass of the Congo will not allow free passage. The GEM has a marked advantage over other vehicles for operation in

swamp and marsh areas, but it will be limited to open waterways in mangrove swamps, and somewhat limited in areas of dense reeds and marsh grass, such as those in Uganda and southern Sudan.

The most convenient method of assessing the influence of vegetation on GEM size and operating height is to include this feature among the grouping of terrain obstructions and discontinuities, which is discussed in detail in the next subsection.

The significant numbers obtained from consideration of vegetation cover are listed below:

1. Dense forests covering 24% of land area limit GEMs to waterways and other cleared areas, the latter providing free passage only to vehicles not much over 20 feet in width (for GEMs supported by the air cushion, without ground contact);

2. Other forms of vegetation may be traversed by GEMs with greater or lesser degrees of freedom, including marsh and swamp areas heretofore excluded from military vehicle operations;

3. Analysis of vegetation influence on vehicle size and operating height is included in the

next paragraph, among terrain obstructions and discontinuities.

(5) Terrain Obstructions and Discontinuities

The Ground Effect Machine supported on its air cushion does not have the surface contact which provides traction for wheeled and tracked vehicles. Its performance in areas of terrain obstacles and discontinuities is limited to operation above such obstacles, or penetrating them by utilizing vehicle momentum and propulsive thrust.

The classification of obstacles is of significant importance in GEM design for operation in a given area. For overland operations on a world-wide basis, terrain obstacles and discontinuities can be grouped into three categories:

1. Solid
2. Yielding, passable
3. Yielding, non-passable

Solid obstacles include walls, buildings, dikes, and embankments, large trees, ditches, rocks and other objects whose contact by the vehicle may cause serious structural damage or personnel injury.

GEM structure must be designed for very infrequent contacts of this type. For most operations, however, the vehicle must clear all such obstacles.

Yielding, passable obstacles include grains, most grasses, light fences, and other obstructions where contact by the vehicle is not likely to cause damage or injury, and where vehicle momentum and propulsive thrust is sufficient to provide passage without much loss of speed. For most operations, GEMs will be able to operate below the maximum height of such obstacles, although not with complete ignorance of them.

Yielding, non-passable obstacles include dense brush, tough grasses and reeds, cane fields, and thick hedges. Contact with these obstructions is not likely to cause vehicle damage or personnel injury, but momentum and propulsive thrust will be insufficient to penetrate continuous coverage of these obstacles. Operating heights in such areas must be at least sufficient to just brush the top of such obstacles except where they are sparse.

The variety and dimensions of terrain obstacles and discontinuities throughout the world are almost endless. Significant obstructions peculiar to the continental

areas are briefly listed in Chapter I, and a great many more are included in the data appendix. On a world-wide basis, however, these obstacles and discontinuities can be categorized by a few numbers having significance for overland GEM vehicle classification.

Many of the solid obstacles are associated with drainage features, natural and artificial. A GEM operating on an inland waterway is limited if it has no access to the adjoining shore. Moreover, a GEM operating cross-country must be able to cross streams which intersect its route and, consequently, must be able to climb and descend stream banks.

In many areas of the world, streams are steeply entrenched in gorges and canyons. These areas must be ruled out for GEM operations, except where an entry and exit point can be found. Even in the majority of areas where stream banks are low or not generally steep, the necessity of entering and leaving the stream area poses a formidable requirement for the GEM.

Almost everywhere even minor streams much too small to use as access routes have vertical banks 5 feet high and steeply sloping banks (30-100 per cent) 10 feet high. The ability to traverse these banks is a necessity for all but the most limited overland operations. An

immediate result is the severe limitation imposed on the small GEM vehicle, certainly on all GEM vehicles with an effective base diameter less than about 30 feet.

Artificial embankments, dikes, and levees are also significant obstructions. These are common in lowland regions of most of the world's nations. Although slopes of earth embankments are generally only 30-50 per cent, heights of 10 feet and over are common, and flood dikes along some of the world's major rivers in Europe, Asia, and Africa are over 20 feet high. Banks of navigation canals are generally steep, over 100 per cent, but not over 10 feet high.

Irrigation ditches and canals are important in lowland areas and the lower parts of river valleys, especially in southwest and southeast Asia. Size, shape, and spacing of these features vary greatly from area to area. Generally, irrigation ditches are from 2 to 10 feet deep and 4 to 30 feet wide. Some are elevated above the level of the plain, but many are incised. These are partly filled with water during the growing season, but in the non-growing season they may be empty.

In the plains of northwest and eastern Europe, in India, Thailand and Burma, the proportions of 3:1 width-over-height ratio are common for most irrigation features,

with earthen banks having slopes to 100 per cent. Extensive areas of rice paddies and other wet cultivation crops in southeast Asia are divided into small fields, perhaps 100 feet square, separated by dikes about 2 feet high and wide. These paddies are dry in the nongrowing season. Where irrigation features are most numerous, reconnaissance will be necessary before extensive GEM operations can take place.

Among the other important solid obstacles are densely built-up areas with buildings, walls, and many fences. Generally, the dense urban areas must be bypassed in all GEM operations except those restricted to waterways. Not only the clearance problems, but also the effects of downwash and noise will necessitate this result.

Even in nonurban areas, groups of buildings must be bypassed. Walls and embankments are more generally common and must be crossed. In western Europe, walls in rural areas are usually 2-6 feet high and 2 feet wide. On many hillsides in generally rough areas, terraced cultivation uses steps of 2 to 5 feet height, with widths of 10-100 feet. If these terraces are walled, GEMs will probably be excluded by the combination of slope and wall.

In flood plain areas, roads and railroads are commonly situated on embankments 3 to 6 feet high. These are common, particularly in eastern Europe and in China. Even in the Arabian Deser , stretches of oil-pipelines lie above ground, with diameters of 3 feet. [illegible] fallen trees, logs, railbeds, and rocky areas [illegible] other significant solid terrain obstacles, mostly 1 to 3 feet above ground level.

For world-wide operations, a minimum normal operating height of 2 feet will be required, except for very limited areas. For all but local operations, the ability to climb and descend a vertical 5-foot bank will be required. This jump capability can probably be accomplished by some diversion of propulsion and control power to the lift system, since it will only be required for very short periods of time.

In addition to the 5-foot vertical bank, a cross-country GEM will have to be able to rise over a 4- to 6-foot solid obstacle. Additionally, it should have the ability to climb a 10-foot bank of 50 per cent to 100 per cent slope, for many operations.

It is obvious that the requirement for traversing these solid obstacles will have a major influence on operating heights and power requirements. In particular,

the usefulness of the small scout car type vehicle is seriously doubted, except in very limited areas.

The yielding obstacles, passable and nonpassable, are not quite as severe a limitation on GEM design. Hedges, elephant grass, and marsh reeds are all in the 10- to 15-foot height range. Dense brush ranges from low growth to 20-foot thornbush in east and south Africa. Cultivated low trees and tall grasses such as coffee and sugar cane are also 10 to 15 feet high. Where the growth of these trees, grasses, and bushes are too thick to penetrate, they will not be narrow enough to "jump" over, even by a large machine.

The taller yielding nonpassable obstacles must, therefore, be bypassed or cleared, where they are dense. The clearing process is not as difficult as that associated with dense forests. In addition to tall brush, many areas are more or less covered by dense short brush and brambles 2-3 feet high, such that a normal operating height of at least 2 feet will be necessary in these locations.

The yielding, passable obstacles such as grasses, grains, and light fences, also vary greatly in size and distribution. Barbed wire fences are generally 3

to 5 feet high. Grain is normally 4 to 7 feet high in the growing season, but with dense stubble not over 2 feet high. Savannah tall grass is up to 15 feet tall in many parts of Africa, but most other grasslands are 3 to 5 feet high. A 2-foot operating height is sufficient in most of these areas.

The extent and nature of obstacles will also have significant influence on operating speeds. Unless operations and cross-country routes are carefully planned in advance, it will be necessary for the GEM operator to discern and traverse terrain obstacles and discontinuities. Where these are numerous, cruise speeds must not exceed those which would allow him to judge the nature of an obstacle and carry out the necessary maneuvers, within the limits of the low control accelerations common to almost all Ground Effect Machines. Previous cross-country vehicles have not had the potential for the high speed performance which can make the problem of recognizing, judging, and traversing cross-country obstacles as serious as it is for the GEM.

The determination of adequate operator-machine response characteristics to terrain obstacles is an area requiring further study. For the present, some restraint must be exercised on expectations as to average cross-country GEM speeds, as these will probably be

much less than the 80 to 100 knot performance capabilities being considered for these machines

The previous paragraphs have covered the environmental factors having major influence on the size, operating height, and available operating areas of overland Ground Effect Machines. The remaining environmental factors, listed in Table 12, have influence on GEM auxiliary power, design, and equipment requirements, but not so much on size and operating heights. These include wind, sand, and dust, other climatic factors, induced environment factors and combat environment factors. Discussion of some of these areas is included in Chapters III and IV.

From the material in the preceding pages, the classification of GEM vehicles for overland military operations can be developed. It must be remembered that this classification is based entirely on the environmental requirements, and that consideration of vehicle performance is being left to the discussion of Chapter IV.

The results, in terms of world-wide overland GEM operations, are as follows:

(1) Vehicle Size:

Limited primarily by lateral clearance for operation in stream valleys and through cleared areas in forests;

20-foot width usable on about 95 per cent of streams with adequate clearances;

30-foot width usable on about 75 per cent of streams;

50- to 60-foot width usable on major rivers only, except throughout most of central Africa, the Amazon Basin, western U.S.S.R., southern China, and India;

20-foot width about maximum for operation in forest clearings other than waterways.

(2) Vehicle Operating Heights

1. Continuous Operation

1 foot for limited local operations on open plains and desert areas;

2 feet for general operations over plains, grassland, cultivated areas, and sparse low brush, with some detours;

3 feet for general overland operations with fewer detours.

2. Jump Capability

4 feet for limited operation across walls, rail embankments and low dikes;

6 feet for general operations in open areas;

3. Terrain Discontinuity Capability

5-foot vertical bank up or down for crossing almost all stream valleys, and irrigation ditches when empty.

4. Slope Requirements

15 per cent continuous slope for limited operations;

30 per cent continuous slope at low speed for general operations, with 15 per cent continuous slope at normal speed;

50-100 per cent slope 10 feet high for exit from many rivers and crossing dikes and levees.

(3) Operating Speeds

1. Inland Waterways

30-40 knots for traversing bends in rivers; 60 knots suggested design cruise speed.

8. Terrain Obstacles and Discontinuities

Average cross-country speeds limited by obstacles, further study required in this area.

The suggested classification for overland GEM vehicles is given in Table 13.

The family of vehicles classified in Table 13 covers configurations which are considered practical within the present state-of-the art. Superimposing these configurations on the environmental factors summarized in the preceeding pages gives the operating capabilities of each size vehicle in the overland natural environment.

The choice of rectangular planforms with length to width ratios of 2 is arbitrary, although these proportions are nearly optimum for the power/size compromise. The operating heights and jump capabilities shown represent attainable performance, although not necessarily economical performance. In fact, it would be advantageous to have the smallest size vehicle, 10 x 20 feet, with a normal operating height of three feet and a jump capability of six feet. This performance is beyond the available state-of-the art in regard to stability, and also would require uneconomical amounts of power.

Table 13
Overland GEM Classification

Class	Size (Feet)	Operating Height (Feet)	Jump Capability (Feet)	Slope Capability (Per cent)	Land Area Usable (Per cent)	Inland Waterways Usable (Per cent)	Access to Stream Valleys (Per cent)
I.	10 x 20	1	2	15	6	90	5
II.	20 x 40	2	4	20-30	18	90	20
III.	30 x 60	3	6	30	34	75	30
IV.	40 x 80	3	6	30	32	60	30
V	50 x 100	3	6	30	28	50	25

In general, operating utility increases with increased operating height, but at heights above three feet for normal operation, and six feet for jump capability, the rate of increase becomes very small. By maintaining the three and six foot heights, larger vehicles would be able to operate at a lower height-to-diameter ratio, with corresponding increased economy. On the other hand, increase in vehicle size tends to restrict operating areas, in regard to lateral tolerances. Although the 40 x 80 foot GEM and 50 x 100 foot GEM would operate at lower specific powers than the 30 x 60 foot GEM at the same heights, their area usability would not be as broad.

The accessibility of stream valleys is important for both crossing and waterway use. The small vehicle (Class I), with its low operating height, is very severely limited in getting in and out of stream valleys. Even the larger vehicles will be quite restricted in this respect. The column headed "Per cent Access to Stream Valleys" indicates the available access area along the stream valleys rather than the number of stream valleys which are accessible.

Table 13 indicates clearly the range of operating suitabilities for ground effect machines as derived from the worldwide environmental data. The optimum vehicle, from the point of view of utility, is the smallest vehicle which can operate at three feet during cruise and at six feet for

earance of obstacles. The 30 x 60 foot vehicle fits this category. Larger vehicles will be more economical, and will have perhaps less severe stability problems; but will have a somewhat smaller range of usability.

4. DISCUSSION AND CLASSIFICATION OF MILITARY GROUND EFFECT MACHINES - AMPHIBIOUS

The world-wide environmental data for amphibious operations of Ground Effect Machines are summarized in Chapter I, Section 4. The background data are contained in Appendix C.

Since the amphibious capabilities of the GEM are one of its primary assets as a transportation system, there is an inherent overlap of GEM amphibious operations and those which have been designated as marine, and overland. Rather than rationalizing why an operation on inland waterways is overland, while one on coastal waterways is marine; this study develops vehicle classifications in terms of the most appropriate operating area, regardless of the fact that overlap exists.

In this context the amphibious operations spectrum covers land-water operations in the coastal areas of the world. Generally the inland penetration is considered to be no more than 20 to 30 miles, but in areas of stream valley approaches this is not a strict limit. The overwater

ortion is limited to ranges less than about 200 miles; this may be an unloading operation from a ship at sea, a traverse of a small body of water from another land area, or a land-based sea patrol.

The classification of amphibious GEMs necessarily contains most of the factors affecting both marine and overland operations except high altitudes and long ranges. Table 14 includes the most important environmental factors affecting the basic performance and design parameters of amphibious GEMs, together with the specific influence of each. For the factors of which the influences a[illegible] be similar to those discussed in the preceding sect[illegible]s, referen[illegible] considered sufficient. Where th factors or their influ[illegible] are unique for amphibious opera[illegible]ons, they are discu[illegible]-low.

(1) Coastal Terrain Land[illegible]rms

The generaliz[illegible] landforms, and their suitability [illegible] GEM operat[illegible], have been discussed in Chap[illegible] [illegible] In Chap[illegible] it was concluded that about three-fourths of the wo[illegible]ld's coastline (excluding the Arctic Islands, Greenl[illegible]d, and Antarctica) are accessib[illegible] for at least limited GEM operations. Abou[illegible] per cen[illegible] of the world's coastline [illegible]uitable for GEM access i[illegible]nd. The [illegible]lity of the GEM to [illegible]averse mud

Table 14
Environmental Factors in Amphibious Operations

Environmental Factors	Influences
1. Coastal terrain landforms	Area limitations
2. Coastal drainage features	Area limitations, vehicle size
3. Wave heights and surf	Operating height
4. Surface-piercing water obstructions	Operating height
5. Slope of beaches and near-coast terrain	Power requirements
6. Characteristics of beaches	Vehicle size, operating height
7. Vegetation and surface cover	Area limitations, vehicle size, operating height
8. Terrain obstructions and discontinuities	Operating height, power requirements, speed limitations
9. Temperature	Power plant output, icing problems - Chapter III
10. Other climatic factors 11. Induced environment factors 12. Combat environment factors	Design and equipment requirements - Chapters III, IV

flats, swamp areas, and stream valleys is particularly significant in increasing the number of usable landing places. GEMs will not be able to land on rocky shores, except where penetrated by stream valleys, nor will they be able to surmount sand and earth bluffs unless openings are available. The emphasis in amphibious GEM operations will be away from reliance on a few concentrated beach areas to a wider operating area along a coast. Resupply and coastal lighterage will also benefit from this broadened operating concept.

(2) Coastal Drainage Features

With consideration of GEM amphibious operations through coastal stream valleys, the characteristics of these access routes have a major influence on vehicle design parameters. The tables in Appendix C contain data on the coastal stream valleys in each political unit bordering the coast (these data are distinct from the data on inland stream valleys in Appendix B). Coastal stream valley data include spacing of major streams, width of the water surface and associated length of the stream within this width range, and a notation on the percentage of steep banks near the coast (less than about 15-20 miles), and farther inland.

The characteristics of stream valleys are generally less restrictive near the coast than inland, i.e., shallower banks, wider streams, weaker current. Many delta areas of tidal rivers are partly blocked by sand and mud bars, which would not be obstacles to GEM operations. On a world-wide basis average widths of coastal stream valleys are over 100 feet on 80 per cent of the coastline, over 150 feet on 70 per cent, over 250 feet on 50 per cent, and over 500 feet in large areas of Central Africa, the Amazon Basin of South America, India, and many other major rivers. Most of the rivers over 250 feet wide are usable at least 50 miles inland, and those less than 250 feet wide are usable from 30 to 100 miles inland. Only about 20 per cent have steep banks near the coast, but about 40 per cent have steep banks more than 15-20 miles inland.

Following the procedure used in the classification of overland GEMs, the limitation of vehicle width to no more than 1/4 to 1/3 of stream width indicates that 30 feet width vehicles should be usable on about 80 per cent of the coastal stream valleys, 40 foot width on about 70 per cent, and 50-60 foot width on 50 per cent. Larger GEMs could be used in many specific locations or a general world-wide basis in displacement operation.

Steep banks near the coast will limit exits from stream valleys on about 20 per cent of the world's coasts, but coastal vegetation will further restrict operations, as discussed in a succeeding paragraph. Operations in the many tropical coastal areas with mangrove and nipa swamps requires navigation of winding channels. This will reduce speed appreciably, probably to no more than 30 knots in many tropical coastal areas.

(3) <u>Wave Heights and Surf</u>

The height of waves and surf will have a primary influence on the minimum vehicle operating height. Although wave heights in coastal areas will be less than those in the open sea, the development of extensive surf and high breakers is a very common occurrence. The GEM must be able to navigate the surf zone in both directions, with the outward passage into the breakers probably more critical in terms of impact loads.

Surf is a function not only of tides, offshore and nearshore slopes and the state of the open sea, but also of local winds and sea states. Almost any exposed beach will have high surf during storms. The GEM cannot be designed for sustained operations in stormy conditions. On a world-wide basis, surf over five feet occurs on 90 per cent of the world's coasts, surf over

8 feet on 30 per cent, and surf over 12 feet on about 5 per cent. With an operating height of one-half wave height, as discussed in the section on marine GEMs, the requirement for operating in the surf zone specifies operating heights as follows:

1. For operations on 10 per cent of the world's coasts, maximum sustained operating height 2.5 feet.

2. For operation on 70 per cent, maximum sustained height 4 feet.

3. For operation on 95 per cent, maximum sustained height 6 feet.

Further specification of operating height is included in the paragraph on terrain obstructions and discontinuities.

(4) Surface-piercing Water Obstructions

For high speed operations over water the GEM must avoid collision with solid surface piercing obstacles. On a world-wide basis, these obstacles (primarily rocks and reefs) are quite evenly scattered on many coastlines. In very few cases, however, are they concentrated enough to seriously restrict GEM operations, so that basic design specifications can neglect this factor. Under water obstructions, which have always plagued amphibious

operations, will be a hazard to any GEMs which are operating in the displacement configuration, whether due to power loss or other cause.

(5) Slope of Beaches and Near-coast Terrain

Amphibious GEMs must have sufficient power to traverse the slopes of beaches and other near-coast terrain. Beach slopes depend on tidal range, surf action and beach material. As discussed in Chapter I, Section 4, there is usually a difference in slopes of the beach zone between the normal low tide and high tide line, and the zone above the normal high water line. Beach slopes range from flat to about 10 per cent in the L.W.-H.W. zone, and up to 20 per cent in the H.W. zone. Average gradients in the two zones are about three and six per cent respectively.

About 80 per cent of the world's beaches have maximum gradients less than 10 per cent and about 90 per cent have maximum gradients less than 15 per cent. Although many coastal areas have short steep stretches, those which have bluffs and cliffs are mostly ruled out for GEM operations anyway. Generally the steady gradients for near coast terrain are less than [illegible] per cent. The provision of 15 per cent slope capability should therefore be sufficient for most amphibious operations.

(6) Characteristics of Beaches

For amphibious operations carried out over beaches, the physical characteristics of the beaches are important. Slope has already been discussed. Length of beaches influences suitability for large scale operations; width of beaches (including tidal ranges) limits vehicle size; beach materials may cause operating problems in terms of dust and damage from gravel thrown up by the GEM downwash; and beach exits determine the usefulness for over-the-beach operations to inland unloading or transfer points.

Although quantitative data on physical characteristics of beaches are not yet available on a complete world wide basis, the following paragraphs are based on analysis of the characteristics of 7000 beaches, including almost all the beaches on the coasts of the Eurasian land mass.

Lengths of beaches are usually differentiated between less than two miles, and over two miles. About 45 per cent of the beaches for which data are included in Appendix C are over two miles long, representing areas suitable for major beach unloading operations.

Width of beaches ranges from a few feet to several miles at low tide, but many beaches disappear at high

tide. Beach widths at high tide, and the tidal ranges, are listed in Appendix C. For unloading operations on the beach, the GEM should be able to sit down entirely beyond normal wave action at high tide. For fore and aft loading this would limit vehicle width to minimum beach widths. The data show that more than 70 per cent of the beaches studied are over 50 feet wide at high tide, and over 25 per cent are over 100 feet wide at high tide. Thus 50 foot wide GEMs could unload out of the water on 70 per cent of the beaches, and 100 foot wide GEMs on 25 per cent.

Beach materials vary greatly, but sand is predominant. It is easily blown about when dry, but quite firm when wet. Ninety per cent of the accessible coasts are composed of sand, mud, pebbles, coral, or a combination of these. The remaining ten per cent include cobbles, rock, shingle, seaweed, clay loam, and debris. The effect of the jet downwash on the surface material is discussed in Chapter III.

The availability of suitable beach exits is one of the differentiating factors between Code 1 and Code 2 coasts as discussed in Chapter I, and illustrated on Figure 14, following page 171. In many cases where the terrain rises steeply from the beach, GEM vehicles cannot penetrate farther inland in these

areas. In some places seawalls and road and railroad embankments also block exits from beaches. Because of the suitability of stream valleys for GEM operations, concepts of operations must be revised to take advantage of these, while placing less reliance on operations in areas where vehicles and supplies cannot be unloaded inland.

(7) Vegetation and Surface Cover

The influences of these factors are similar to those discussed in the section on overland operations and will not be repeated here. Dense vegetation in tropic coastal zones generally means the only inland access will be via stream valleys. See pages 253 to 256.

(8) Terrain Obstructions and Discontinuities

Same as for overland operations. A minimum operating height of two feet, with jump capability of 4-6 feet, is essential for almost all inland penetration. In addition, ability to climb a 10 foot bank of 50 per cent to 100 per cent slope will be necessary in many areas. See pages 256 to 264.

The above environmental factors form the basis for classification of amphibious ground effect machines similar to that used for marine and overland GEMs. In most respects

the land obstacles will be more limiting than those of the overwater part of the amphibious environment.

The important results are listed below:

(1) Vehicle Size

Limited by lateral clearance for operation in stream valleys and by widths of beaches, but not as severely as in general overland operations:

30 foot width usable on 80-90 per cent of coastal stream valleys,

40 foot width usable on 70 per cent,

50-60 foot width usable on 50 per cent,

50 foot width (for end-loading GEMs) satisfactory for unloading above high water line on 70 per cent of beaches,

100 foot width satisfactory for unloading above high water line on 25 per cent of beaches,

20 foot width about maximum for operation in forest clearings other than waterways.

It is important to note that vehicle size may also be severely limited by trans. stability requirements.

This is an operational consideration rather more than an environmental one, but it should not be forgotten.

(2) Operating Height

Determined by the necessity to traverse the surf zone and overland obstacles.

1. Normal Operating Height Overland

1 foot for operations to beaches only,

2 feet for limited inland penetration.

2. Jump Capability

4 foot minimum for crossing walls, dikes, embankments,

6 feet for wider area usability across walls, dikes, embankments,

5 foot vertical bank up and down for access from stream valleys.

3. Maximum Sustained Operating Height Overwater

2.5 feet for clearance of surf in 10 per cent of coast areas,

4 feet for surf clearance in 70 per cent,

6 feet for surf clearance in 95 per cent.

(3) Slope Capability

10 per cent slope capability for operations over 80 per cent of beaches,

15 per cent slope capability for operations over 90 per cent of beaches, and for most near-coast terrains,

50-100 per cent slope on 10 foot banks for access from many stream valleys.

(4) Operating Speeds

Limited to about 30 knots for operations in tropical coastal swamps, also limited by obstacles in the overland phase; no specific numbers can be determined without further experimental work.

A suggested classification of amphibious GEMs based on these factors is given in Table 15.

The vehicles classified in Table 15 range in size from 20 x 40 feet to 75 x 150 feet. The normal operating heights given are the cruising heights over land; the maximum height is the operating height at about half normal cruise speed, and is intended primarily for operation through the surf zone. Jump capability represents the

Table 15
Amphibious GEM Classification

Class	Size (Feet)	Normal Height (Feet)	Max. Height (Feet)	Jump Capability (Feet)	Slope Capability (Per cent)	Access to Beaches (Per cent)	Access Inland Via Stream Valley (Per cent)
I.	20 x 40	1.5	2.5	3	10	10	10
II.	30 x 60	2	3	4	1[illegible]	40	25
III.	40 x 80	3	5	6	15	70	40
IV.	50 x 1[illegible]0	3	5	6	15	70	35
V.	7[illegible] x 150	4	6	6	15	50	30

maximum atainable short duration height for clearance of obstacles. The slope capability listed corresponds to the slopes within the area having the given height ranges. The columns headed Access to Beaches and Access Inland represent the percentage of the world's coastline (excluding Antarctica, Greenland, and Arctic islands north of 77°) which are accessible to amphibious GEMs of each class. This accessibility index is intended to include operations throughout all seasons of the year, but not during stormy weather. On Arctic coasts the occurrence of hummocked ice may restrict operations during a large part of the year.

For GEMs built within the framework of the present state-of-the-art, it can be seen that the 40 x 80 foot and 50 x 100 foot vehicles will have the highest percentage of area usability. It must be kept in mind that this classification is based on the natural environmental framework only, and that vehicle optimization requires much additional information in the areas of mission requirements, vehicle attainable performance, effects of the combat and induced environment, and several difficult specialized problems such as loading at sea, and transportability. Some of these areas are discussed in Chapters III and IV.

III. EFFECTS ON INDUCED AND COMBAT ENVIRONMENTS ON MILITARY GROUND EFFECT MACHINES

1. INTRODUCTION

The effects of the surrounding environment on a specific transportation device are by far the most important considerations when introducing a new vehicle to a military system. A vehicle that is technologically sound, but ill suited to its normal operational environment, will soon find little support from the using agency. From the preceding work on topography, oceanography and climate; sizes of vehicles, clearance heights and speeds have been determined, in an attempt to pinpoint the highest degree of utilization currently achievable. As gains are made in the areas of recirculation, stability and control, channelled hulls and structure weight, clearance heights and speed may well change; but in general, the over-all sizes of vehicles in keeping with the environmental criteria developed will remain. These sizes, together with what is currently considered state-of-the-art configurations are the basis for the data outlined in this chapter. In general, the family of GEMs outlined by Ljungström (26) are considered good examples of these vehicles and can be taken as representing the design "know-how" of today's machines. Accordingly, powerplant arrangements, fan and propeller positions, cargo loading and unloading arrangements, cushion pressures, duct configurations and controls, while a mix of individual contributors,

... generally follow these basic designs. Large, unshielded, forward-facing propeller systems with enormous duct inlets are not considered suitable for true military vehicles and have not been used in any of the subsequent analyses. The high radar reflectivity, limited cargo facilities, the danger of reingestion and other practical considerations strictly limit these designs to prepared surfaces behind the line of any exposed military action.

This chapter places the class of vehicles determined from the previous chapters in a military environment where self-induced and combat features of the vehicles are evaluated to the degree possible from the scant material available. Wherever possible, data have been obtained directly from designers of current equipment and cross-checked for validity with analytical data.

The induced and combat environments are those which affect the operation of the man-machine system and arise from the operation of this system in any natural environment to which it is suited, and in any combat situation for which it is intended.

(1) The Induced Environments

These conditions arise during any operation of the system and interact to a large degree with the natural and combat environments in which the operation is conducted. They originate from characteristic features of the system and its components and may be modification or deviation of, or addition to, the basic design.

(2) The Combat Environments

These arise only during operation in a combat situation, and are interrelated with the natural and induced environments of the situation. The main feature of these environmental considerations is that they will contribute to a deterioration of the effectiveness of the system in a combat situation, unless preventive measures are considered.

The problem areas, the origins of the problem, and the factors upon which they depend, are listed for both induced and combat environments in Tables 16 and 17.

2. INDUCED INVIRONMENTS

(1) Noise Levels

The noise level in the GEM must be controlled in order to provide a satisfactory working environment for the operating personnel. At the same time, such treatment will provide a measure of control over the external noise level, depending on how the basic problem is attacked. A reduction of basic powerplant noise will have the greatest all-around advantage, and if adequate vibration-absorbing and soundproofing methods are utilized, the best over-all characteristics will have been achieved.

The approximate levels of tolerable internal noise are listed below for the total audio range of importance:[41]

Table 16
Induced Environment

Problem Area	Originating From				Dependent Upon
Noise	Powerplant	Structure	Lift system	Propulsion	Power, rotational speed, structural damping
Vibration	Powerplant	Structure	Lift system	Propulsion	Power, rotational speed, structural damping
Heat	Powerplant				Power, rotational speed, structural damping
Exhaust gases	Powerplant				Power, rotational speed, structural damping
Static electricity	Lift system	Performance			Operating height, forward speed
Reduced visibility	Lift system	Configuration			Cockpit design and location, surface conditions
Acceleration and shock	Propulsion	Stability			Power for propulsion and control, response to surface contours
Ingestion	Powerplant	Lift system	Propulsion system		Power, operating height, surface material, local winds
Snow and ice accumulation	Weather conditions	Sea temperature	Lift system	Performance	Power, operating height, surface hardness, ambient weather conditions

Table 17
Combat Environment

Problem Area	Originating From				Dependent Upon
Signatures					
Noise	Powerplant	Structure	Lift system	Propulsion system	As for induced, plus distance, winds, terrain
Dust and spray	Powerplant		Lift system	Propulsion system	As for induced, plus distance, winds, terrain
Profile	Configuration	Performance			Cargo size, operating height
Infra-red	Powerplant				Power, exhaust muffling and cooling
Radar reflectivity	Configuration				Skin finish, geometry, engine exhaust, propellers
Vulnerability	Performance	Configuration	Basic design		Speed, size, armor
Repairs in field	Configuration	Basic design			Simplicity of design, use of modular construction
Loadability	Cargo vessel				Vessel stability, sea state, cargo size, design of loading gear
Nuclear environment	Nuclear combat	Radiation intensity	Blast, flash, temperature		Distance from explosion, magnitude of explosion, GEM aerodynamic design, protective features
Mine fields	Powerplant	Lift system			Ground pressure, noise level, magnetic interference

Frequency Range, Cycles per Second	Sound Pressure Level Reference to .0002 Millibars
Overall (20-9600)	113
20-75	111
75-150	111
150-300	111
300-600	105
600-1200	99
1200-2400	93
2400-4800	87
4800-9600	87

When utilizing a headset and helmet of good design for communication, the maximum ambient noise level for good speech communication is about 100 db.

For normal speech communication without telephony, noise levels should be less than:

approximately 60 db - for normal voice communication
" 66 db - for loud voice communication
" 72 db - for shouted voice communication

Contact with the designers and operators of several current experimental GEMs indicates that the noise level experienced inside the cockpit and in the immediate vicinity of the vehicle are at least high enough to require shouting and ear protection. Maximum noise levels have been measured between 90 and 120 db for some earlier models. Future design is expected to reduce these maximum values predictably, and indications are that for the next generation of GEMs,

cockpit noise levels of the order of 80 to 95 db may be expected, requiring ear protection for continuous use and telephony for adequate operational functioning. It is not expected that external noise levels will be reduced to much below 90 to 120 db.

(2) Vibrations

Vibration is experienced in many forms and orders. The majority of the induced vibrations result as follows:

1. Power Unit Induced

Vibrations induced at the fundamental frequencies of the power unit and at the harmonics of these frequencies may lead to structural damage.

These are transmitted through the structure, and are amplified by structure panels to different amplitudes, if the panels are not adequately supported and damped.

2. Lift System Induced

Periodic fluctuations in the air flow through the air-flow ducting may resonate in the ducting under some operating conditions The frequency of vibration is a function of duct geometry, duct pressure and duct wall stiffness.

It is possible that a similar situation may arise in the base region of the vehicle, at low vehicle heights, when the damping properties of the air cushion are minimized. Periodicity in the airjet flow may induce periodic fluctuations in the cushion pressure which may be amplified by the base structure.

3. Shock Induced

The natural frequencies of the structure may be excited by frequent shock loadings arising in particular from impact with waves during sea operations at low operating heights.

4. Acceptable Vibration Data [41]

Frequency, c/s	Amplitude - inches		
	Imperceptible	Unpleasant & Annoying	Painful to Unbearable
1	< .02	> .02 <2	> 2
10	< .0002	> .0002 < .02	> .02
100	< .00002	> .00002 < .0005	> .0005

Discussions with GEM constructors and operators have shown that, to date, none of the problems outlined here have been experienced to an important degree. A few screws have worked loose, and some structural vibration

has been noticed, but, with careful redesign of details utilizing established design practices, these were soon eliminated.

(3) Component - Generated Temperatures

The sources of GEM-generated temperatures are:

- power units
- human occupants
- fluid dynamic friction

The only significant sources are the power plants. The highest temperatures occur internally in and around the combustion chambers, and externally close to the exhausts. The local temperature rise in the GEM due to these high temperatures depends on:

1. Engine cooling
2. Insulation
3. Conduction through the structure
4. Radiation from the engine and exhausts

1. Gas Turbines

Typically, the surface temperature on the outside of a gas turbine, prior to insulation, or external cooling air, ranges from ambient at the intake, rising

to about 400° F at the combustion chamber, and then rapidly to about 900° F at the jet pipe. With provision of adequate insulation, these maximum temperatures can be reduced to about 350° F and, with external cooling air, to 120° F. Exhaust gas temperatures are of the order of 1500° F.

2. Piston Engines

The distinction is made between air-cooled and water-cooled engines, since appreciably different surface temperatures are inherent in each type.

For water-cooled engines at sea level, the maximum likely temperatures to be met are those associated with boiling water at pressures somewhat higher than atmospheric, with never-exceed values in the range of 120° C to 150° C.

For air-cooled engines, surface temperatures close to the cylinder walls may be as high as 200° C to 240° C, reducing rapidly along cooling surfaces, such as the cooling fins mounted on the cylinders.

Exhaust gas temperatures, in the exhaust manifold, lie in the range 600° C to 1000° C, the lower temperatures being more applicable to low compression ratio engines (4:1 to 5:1), and high-speed compression-ignition

engines, and the higher values are appropriate to high-compression high-speed engines of aircraft type.

3. <u>Effects of Component-Generated Temperatures on Vehicle Operation</u>

In non-combat situations, these resolve into the effects on the structure, and the effects on the operating personnel. In both cases, with no more than the amount of insulation and isolation currently provided for aircraft powerplant installations, no problems will be encountered.

Combat situations as affected by temperature generation are discussed under "Combat Environments."

(4) <u>Exhaust Gases</u>

The exhaust gas level is only of importance at low and zero forward speeds, where reingestion of the cushion air may trap substantial quantities of gases, and create a noxious atmosphere in and around the crew compartment. No experience of adverse effects have been quoted. If the exhaust stacks of the powerplants are located diametrically opposite the crew compartment and directed away from it, the possible reingestion will be minimized. It may be necessary at low and zero forward speeds to provide some form of forced ventilation in the crew area, which will be quite a simple matter.

Probable exhaust gas compositions that may occur in practice are as follows:

Engine	Reciprocating			Gas Turbine		
	Weak	Normal	Rich	Weak	Normal	Rich
Nitrogen	77	77	77	77	77	77
Oxygen	10	1	0	19.6	17	17
Carbon Dioxide	6	13	6	1.5	3.4	1.5
Carbon Monoxide	0	1	12	0	0	3.1
Inert Gases & Water	7	8	5	1.9	2.6	1.4

(5) Static Electricity Potentials

1. Sources of Static Electricity Potential

(1) Aerodynamic friction

in hover - the lift system,

in forward motion - the lift system and flow past the structure

(2) Airborne particles - sand, dust, dirt, moisture, snow, resulting in precipitation static approximately proportional to V^3

(3) Fueling processes -

(4) Atmospheric - electrostatic induction from charged clouds

The question of static electricity potential is of some concern since quite high potentials have been discharged from helicopters and aircraft on returning to the ground after operation at altitude. In addition, static electricity potentials have been developed during fuelling and defuelling operations, presenting an explosion hazard.

From discussion with Mr. Enock Durbin at Princeton University, the following points are pertinent.

The atmospheric charge induced by aerial vehicles is a function of the altitude at which they fly; the charge inherent in the atmosphere increases with altitude, increasing most rapidly in the first 5000 to 10,000 feet. Close to the ground, the rate of increase is approximately 1 volt per centimeter. A helicopter flying to 5000 feet will acquire a charge of 50,000 volts, which is then discharged on contact with the ground.

A GEM is unlikely to fly much higher than 5 to 6 feet, which corresponds to a charge of approximately 150 to 200 volts, and it is possible that aerodynamic friction may double these values. The energy stored in the GEM is a function of this charge and the GEM-to-ground capacitance. A typical value of this capacitance is approximately 100 micro-micro-farad. Under these conditions, the energy stored is 2.0×10^{-4} to 2.0×10^{-2} millijoules. The total electrical resistance of an operator may be anywhere from

10,000 to 500 ohms, depending on the moisture content at the contact point, the type of clothing and the ground condition.

The initial value of current discharge through an operator on the ground, in this typical situation, varies from 40 milliamps to 0.8 amps, although 8 to 15 milliamps is about the maximum steady current discharge through an operator that is acceptable. The time constant of the GEM/operator electrical circuit is such that the discharge current drops to less than this within 2 millionths of a second.

Hence, with the order of resistances, charges and capacitances involved in typical GEMs, the current level experienced during discharge will not be at a high enough level for a sufficient period to disable operating personnel.

From experiments with a rolling fluid transporter, it has been stated that an energy level of .2 millijoules is necessary to ignite an explosive mixture of JP-4. Since the energy level contained in a GEM may be of the order of 2.0×10^{-4} to 2.0×10^{-2} millijoules, it is not anticipated that atmospheric or aerodynamically induced charges will constitute a danger.

Aerodynamically induced charges arise from friction between the moving fluid and the vehicle, and between

particles carried with the fluid and the vehicle. These may be either negative or positive charges, and so may increase or reduce the induced charges. It is not expected that these charges will more than double the induced charges; as indicated above, the problem is still not severe.

A complete and practical solution to this problem exists since any form of intermittent contact with ground by a conducting material such as, metal, conducting rubber, etc., combined with complete and adequate electrical bonding throughout the machine, will prevent build-up of the charge, and hence eliminate the need for concern over the problem of static electricity.

(6) Visibility

Basic daytime visibility should, first of all, consist of a complete field of view with the minimum of structural features obscuring line of sight. The actual range of visibility will depend to some degree on the operating height of the vehicle. Visibility in rain or heavy mist and spray can be assisted by direct vision devices, such as are currently used on ocean-going ships and were utilized on the SR.N1 for English Channel operations. The visibility necessary for nighttime operations or operations in fog will have to be provided as usual by some kind of radar terrain detection device.

In addition to vehicle configuration limitations, and natural environment, visibility may also deteriorate with GEMs when operating at zero or low forward speeds (up to about 10 knots) over certain types of surface, due to particles being dislodged and thrown vertically by the air curtain. It has been the experience of GEM operators that hovering over water, sand, snow, or loose dirt produces a cloud of particles that completely envelope the vehicle, thus severely reducing the visibility. This same cloud makes it difficult for ground personnel to operate near the vehicle without protective clothing.

The cloud of water droplets, sand, or dust is a familiar one to helicopter operators and its effects are well known. For example, during take-off in a helicopter from snow-covered terrain, if any time is spent hovering, a "white-out" occurs, and it becomes extremely difficult for the pilot to control the helicopter in order to rise above the snow cloud or set the machine down. Such conditions tend to preclude helicopter operations unless adequate basic stability in hover can be provided, to enable essentially a "hands-off" take-off.

A "white-out" can also occur with a GEM, but the problem of stability and control does not arise, since the vehicle can be inherently stable in hover. As soon as

forward speed is established the "white-out" condition disappears, provided adequate means are available for clearing the windshield.

This is the most severe condition for both a GEM and a helicopter. Similar situations arise in sand and dust environments when the visibility is reduced so that visual clues are lost, and in each case the GEM is able to move out at will, whereas the helicopter has difficulty.

Forward motion restores visibility in forward directions and for forward located cabins, in side directions also. Visibility rearward improves as speed increases, but is still somewhat affected by dust or spray patterns that trail the vehicle. Windshield cleaning devices are essential for operation in sand, dust, snow, ice, or water.

A measure of the heights to which particles are projected is given in the Combat Environment section under "Dust and Spray" (Figure 15).

(7) <u>Acceleration and Shock</u>

These two conditions are basically the same in that they are acceleration phenomena, but they differ in origin and consequently in magnitude and duration.

"Acceleration" in this context refers to steady or slowly changing accelerations brought about by control of

the vehicle or by the response of the vehicle to operating conditions and surface conditions, without contact. "Shock" arises essentially from contact with the surface or obstacles, and is of a very short duration, high-magnitude character.

1. Acceleration

The "accelerations" of importance are those due to dynamic response and applied maneuver forces, and are considered longitudinally, laterally, and vertically, at or near the center of gravity, and at the vehicle extremities.

At center of gravity:	Vertical Longitudinal Lateral
At nose and tail:	Vertical (pitch) Lateral (yaw)
At sides:	Longitudinal (yaw) Vertical (roll)

(1) Center of Gravity Accelerations

Longitudinal. The maximum will occur during braking and accelerating.

Max. effort speed increase	+ .2g
Max. effort braking	- .5g

Lateral. Maximum during maximum effort turns.

Max. effort turn $\pm .1g$

Vertical. Maximum when traversing undulating terrain or smooth swells at sea.

Over waves where - $\left(\frac{\text{wave height}}{\text{operating height}}\right) = 0.5$,

accelerations from $+.3g$ to $+.4g$

(2) Other Accelerations

The accelerations at the remaining locations are not susceptible to generalization since they are very dependent on vehicle geometry and must be evaluated on an individual basis for each configuration.

2. Shock

The magnitudes of shock loadings depend on the location in the vehicle at which measurement is made; positions furthest from the center of gravity are liable to the most severe shock loadings.

Ground Effect Machines present a radically different problem than any other vehicle when assessment of dynamic response and consequent shock loading is desired. The combination of low damping about and along all axes, and poor controllability (by comparison to other

vehicles), and the lack of basic understanding of the dynamic nature of the ground effect phenomena make this assessment difficult.

The only thorough study available to date is that conducted at Saunders-Roe on the SR.N1 and its developments.[29] For these vehicles, the design stressing condition was a 12g impact at the bow. A series of model tests were conducted to determine, with the aid of an analog computer, the coefficients of the equations of motion for the vehicle series. The resultant motion analysis showed good agreement with the test results, and predicted accelerations at the bow on impact with waves on the order of 9g's within the operational speed range of the vehicles. Higher speeds, approximately twice those for normal operation, developed bow accelerations with impact of roughly twice this magnitude. The corresponding accelerations at the vehicle center of gravity were on the order of 3.0 to 6.0g. Immersion of the bow on impact tends to reduce these values by approximately 30 per cent.

These values were evaluated for operation over a sea with waves of sinusoidal form, with wave heights of 1.5 times the vehicle operating height. Experience with the SR.N1 has shown that operation in random seas with wave heights of twice this magnitude is possible

for the same impact accelerations.

It is not within the scope of this study to modify or extend these data in a general way to cover all vehicles. It is believed that the stressing conditions utilized for the SR.N1 may be applied judiciously to many sizes of over-water vehicles, provided the desired operating conditions are similar.

(8) Re-ingestion of Downwash Air

This is one of the more pressing problems associated with GEM operations, creating as it does overhaul and maintenance problems and a reduction in performance when operating in sea, snow, and sand environments, in particular, and on a loose surface in general.

The re-ingestion of salt spray, snow, or sand has been a problem for helicopter operations for some time, resulting as it does in a loss of engine performance, combined with erosion of the compressor and stator blades, and the lifting rotor blades. The mechanisms that result in performance reductions are:

1. Salt incrustation resulting in reduced mass flow through the engine and lift systems and corrosion, if left unchecked for a few hours in tropical conditions.

2. Icing - with broadly the same effect as salt

incrustation, coupled with the general comment that operation in loose snow in sub-freezing temperatures will result in a heavy incrustation of snow on the vehicle, increasing its gross weight, reducing its operating height, and severely limiting the operator's visibility.

3. Erosion and pitting due to the impact between high-velocity water, ice, or sand particles, and high speed compressor and lift fan blades.

A discussion of the comparative behavior of helicopter and GEM lift system may assist in highlighting re-ingestion effects for GEMs.

Helicopter downwash velocities are of the order of 30 knots to 60 knots, whereas typical GEM jet velocities are of the order of 100 knots to 150 knots. This is offset by the relative mass flows through the lifting systems. For vehicles having comparable disc loadings and base loadings, and the same weight, studies indicate that the helicopter mass flow is in the region of 5 to 10 times that of the GEM. Hence, because of the higher velocities, a wider range of particle sizes will be carried into the airflow of the GEM, but due to the smaller mass flow, smaller absolute quantities of material will be entrained.

The GEM downwash jet is a much more concentrated

airflow than that of the helicopter, and when operating at zero or low forward speeds over loose material, snow or sand, tends to create a depression in the surface, which redirects the jet into a high trajectory away from the vehicle. This redirected jet is still much more concentrated than a similar helicopter flow field, and in consequence tends to provide a higher concentration of entrained particles, than the redirected helicopter downwash. A much higher proportion of the total entrainment will be recirculated through a GEM rotor than through a helicopter rotor.

It should be noted that the intake area of the GEM lift fan will be considerably less than the disc area of the comparable size helicopter, and hence the intensity of entrained particles arriving at the fan intakes may be considerably higher than that arriving at the rotor disc of a helicopter of the same weight and loadings. These particles will tend to be of the order of desert sand; the larger particles, being too heavy to be carried by the recirculating velocities, will return to the ground.

Since the GEM intake velocity will be comparable with the jet exit velocity and hence appreciably higher than the flow velocity developed through a helicopter rotor, and since the GEM lift-fan speed will most likely be higher than the helicopter rotor speed, it is likely that the

relative velocity between fan blades and entrained particles will be appreciably more than that experienced by the helicopter and rotor blades, except towards the tip. This, combined with the higher density of entrained particles will present an appreciable erosion problem, and a considerable likelihood of ice and salt incrustration under appropriate operating conditions.

These comments have been made primarily with respect to the lifting fan system, but the same problems exist to no less a degree as far as the main engine ingestion is concerned.

(9) Salt Water Ingestion

An investigation of salt water ingestion by gas turbine engines in helicopter operations,[30] has shown that in continuous operation close to the water an ingestion rate in excess of 10 cc of salt water per minute would have been experienced for each engine (the power plants were 2 T58 engines). The drop sizes ingested at the low altitudes ranged from 2 to 500 microns of which half are in the 20 to 80-micron category.

The effect of operation near the water is also shown on the engine power available, which reduced by some 20 to 2[illegible] per cent after about 4 hours, remaining constant from this time on. These power losses are mainly caused by salt

deposits forming on the compressor blades, being retained there by a very strong inter-molecular mechanical bond, described as "Van der Wall's forces." These deposits thicken and roughen the blades creating poor compressor flow characteristics and reduced mass flow.

An additional long-term effect of this salt incrustation is the development of corrosion pitting due to galvanic action between the ionized salt (which absorbs moisture when the engine is not operating) and the conducting metal surface.

The methods adopted for control of salt deposits comprise washing, inhibiting, and blade coatings, each of which adds some very desirable measure of prevention.

The washing procedure comprises a generous flushing with fresh water daily with the engine cool and rotated on the starter, followed by five minutes minimum at idle power to dry out the engine.

The inhibiting procedure consists of spraying a special oil with additives into the inlet as the engine slows down after switch off; this has the effect of displacing any remaining water from the blades.

Blade coatings are utilized to diminish the galvanic action between the salt and the conducting metal, and are completely effective. The choice of coating is dependent

on the engine temperature condition, while all coatings are susceptible to erosion from sand and dirt, indicating the need for periodic recoating.

These control methods are successful and may be applied equally well to the GEM lift fan and duct system, and to some extent the outside vehicle skin.

(10) Sand and Dust Ingestion

Test results reported[48] on the T53 helicopter gas turbine indicate the extent to which current engine designs can be developed to withstand the severe sand and dust environment likely to be experienced by GEMs.

A formal test program was conducted on a T53, in which 50 30-minute consecutive runs were made, simulating 30-minute missions in a sand and dust environment. The sand and dust particles introduced into the engine ranged through 105-210 microns in size, at a concentration of .010 grams per cu. ft., representing operation in ground effect for 5 hours, and sizes through 0 - 80 microns at a concentration of .001 grams per cu. ft., representing operation out of ground effect for 20 hours.

At the end of the test, [illegible] per cent loss in horsepower had occurred, a 10 per cent loss in specific fuel consumption was evident, and some sand-blast erosion was apparent in the compressor section. No blockage of air

cooling passages had occurred, and the air filter and oil system were free of contamination. When the eroded parts had been replaced, all of which were field replaceable, the power and consumption were within 1 per cent to 2 per cent of the normal value.

A user test program was also conducted with a Bell YH40 helicopter at Yuma, Arizona; over a period of 40.5 hours, 14 hours were spent in ground effect.

This was a much longer duration test than the formal one, including 3 times as much time "in ground effect," and yet no power loss was reported, and only 1.5 per cent in specific fuel consumption. When the engine was examined. the erosion was very mild, and confined to the axial compressor section.

This indicates that the sand and dust environment at Yuma, combined with the flow field about the helicopter, did not create as much ingestion as had been utilized in the formal test, in which 65 pounds of sand had been run through the engine. This suggests that the proportion of sand particles of the sizes used in the formal test was quite small in the desert test, and that the rotor downwash velocities were too low to permit the more numerous larger particles to be carried to the intake by the recirculating stream. Hence, the formal test conditions could be

considered extreme as far as simulating rotor-induced sand concentrations are concerned, thus showing the capability of current engine designs for these operations.

In summary, although the mass flow of a GEM could be much less than a similarly loaded helicopter, the jet velocity will be considerably more than the rotor downwash velocities, by a factor of 2 to 3, thus permitting entrainment of larger particles than those considered in the helicopter test. The entrainment will become more concentrated due to the action of the jet on the ground, and will be directed more towards the vehicle than is the case for the helicopter. Combined with this are the facts that the GEM intake area is much smaller than the helicopter rotor disc area, (and is comparable with the jet exit area,) and the intake velocities will be much higher than the flow velocities through the rotor blades. Thus the concentration of entrained particles will be at least as high as for the helicopter and probably much higher. Erosion can be expected to be severe, particularly since the fan blade linear velocities will be comparable to those of the rotor, in the regions of 0.6 to 0.7 Mach. number. As far as engine designs are concerned, current state-of-the-art seems to be quite capable of accounting for sand and dust ingestion.

(11) Snow and Ice Accumulation

Experience with ships and aircraft operating in the Arctic and Antarctic latitudes indicates that very severe snow accretion and icing conditions can develop that will build up large quantities of ice on the structure of any vehicle operating on or near the surface.

Three particularly severe conditions arise:

1. The accumulation of snow on stationary vehicles, during snow storms, natural or induced.

2. The accumulation of ice on leading edges and propeller blades at forward speed.

3. The accumulation of ice on vehicles operating over water, when the water temperature is above local freezing, while the air temperature is below freezing.

The first problem is a familiar one in operation of vehicles and aircraft in these areas and can be tackled in the same way as for current vehicles.

The second item is again a familiar one in aircraft operations, except that more continuous developments of such icing conditions may be expected, when compared to aircraft which can be operated above or below the icing

level and hence in general only have to contend with the problem during part of a mission.

The third item is of great importance and is particularly experienced by ships at sea in these areas. Wartime experience of convoy operations to Murmansk, and experience of fishing fleets in the Iceland area, has shown how very large quantities of ice can accumulate on a ship's superstructure under these conditions, leading in some cases to an unstable condition in roll (a negative metacentric height, due to the now top-heavy superstructure) which results in capsizing and loss of ships and crew.

For GEMs, the problem is different and somewhat less catastrophic, although still severe in terms of carrying out any given mission.

By virtue of the current type of lift-producing mechanism, the GEM develops appreciable spray, which in hover and at low forward speeds envelopes the machine. Under the severe icing conditions quoted, this spray will immediately freeze on contact with the machine, except in areas of higher temperatures near the engines and exhausts, and will continue to build up as long as these conditions are maintained. In fact, as the icing builds up, the vehicle gross weight increases and the cushion pressure

increases. If constant power is maintained, the operating height will decrease approximately as the inverse of (cushion pressure) with very little change in jet velocity and mass flow. Since the amount of spray generated is a function of jet velocity and mass flow, the same rate of ice build-up will continue. If power is increased to maintain height, however, the jet velocity and the mass flow will increase nearly in proportion to the increase in cushion pressure or gross weight; this in turn means that more and larger water particles will envelope the machine, and rate of ice growth will accelerate. This implies that the simplest way of reducing the severity of icing conditions in hover is to reduce power, and hover at the lowest possible height.

When resting on the water, or when operating at an appreciable forward speed such that the spray generated by the lift mechanism is essentially left behind, practically all of the icing will result from the super-cooled water vapor present in the atmosphere-- this will not be as severe as the hover condition, but will certainly result in a "glaze" ice coating on the vehicle at rest, and ice build-up on the forward portions and fans and propellers at forward speed. In addition, if weather conditions are such that a sea mist is encountered at subzero air temperature, very rapid ice build-up will again result.

I. COMBAT ENVIRONMENTS

The success of an operation will depend upon the element of surprise.

In order to proceed with the minimum chance of detection, various aspects of these vehicles must be carefully controlled. These include:

- noise,
- surface disturbance,
- radar reflectivity,
- infrared emanation,
- visibility and camouflage techniques.

In addition to the element of surprise, the susceptibility of the vehicle to enemy action must be considered. The following aspects of vehicle utility are discussed:

- vulnerability,
- damage protection,
- operation in mine fields,
- nuclear explosions,
- loadability at sea.

(1) Noise

The source of GEM noise is primarily the power plant, secondarily the air flow. If the noise due to the power

plant, including that part of the over-all noise level that is amplified by the structure, can be reduced to the same level as the aerodynamic noise, a GEM would be virtually undetectable on this score.

The only way that this could be approached currently (and the power source is still in the experimental stage) is by the use of fuel cells powering electric motors to drive the lift fan. However, more immediate power plants will be gas turbines and piston engines. Current gas turbines and piston engines require considerable effort to silence them, with consequent appreciable power losses and additional equipment weights.

In order for detection to be possible, the noise level at the detector due to the GEM must exceed the random noise level at the detector location (which typically would be a coastal strip, where random noise would be generated by the sea, wind, disturbed vegetation, etc.). If GEM noise can be kept below the average random noise level, then the chances of detection from noise are much reduced.

Such average random noise level would be below that for normal conversation, but above that for a whisper, say, 40 to 50 db (ref. .0002 millibars). However, this also is about the noise level of the lift-system airflow, and is well below the level from engines and fans.

The variation of sound intensity with distance has been measured for a wide range of air and ground vehicles.[24]

From these data, intensity level as a function of power has been approximately evaluated, such that at 500 feet, the noise level in decibels is

$$dB = 12 \log HP + 59.$$

The rate of change of noise level with distance has also been derived as approximately

$$\frac{d(dB)}{d(\log S)} = 22 \text{ to } 23 \quad (\text{where } S = \text{distance in feet})$$

for aircraft which gives Δ dB = - (6.5 to 7.0) for each doubling of distance, within a distance range of 100 to 5000 feet. This is very close to the theoretical for sound dissipation with no attenuation or reflection or atmospheric disturbance. These factors will, however, play a large part in the value of noise level noted at any distance from a sound source.

From theoretical noise-level studies[43] conducted on various GEM designs, the following approximate noise levels appear likely for GEMs designed to the current state-of-the-art.

Major Over-all Sound Pressure Levels at Source, db	
Engines (turbine and piston)	$(12 \log_e HP + 95) \pm 10$
Lift Fans (4 to 6 blade, 50 to 150 HP per fan, tip speed less than 1100 feet per second)	130 to 150
Over-all Sound Pressure Levels Approx. 1 yd. from Vehicle, db	
In line with Intakes (propulsion, lift)	110 to 130
In line with Exhausts	110 to 130
Elsewhere	90 to 110

The reduction in noise level due to spherical spreading of the sound pressure waves through the atmosphere is given as a function of distance from the vehicle, and is the same for all frequencies.

100 yards	-40 db
1000 yards	-60 db
10,000 yards	-80 db

In addition to the spreading, there are attenuation effects that are a function of atmospheric conditions and the frequency of the sound pressure waves. These attenuation effects are due to the viscosity, heat conduction,

oxygen and nitrogen molecular diffusion, heat radiation, and scattering properties of the atmosphere. The figures below give approximate values of attenuation for standard atmospheric conditions.

	Attenuation in db			
Distance (yards)	Frequency (cycles per second)			
	10	100	1000	10,000
100	.0007	.0038	.313	31.2
1000	.007	.038	3.13	312.
10,000	.070	.380	31.3	3120.

Typical ambient noise levels for various normal environments are as follows:

Jungle (calm day)	40 to 50 db
Coast (calm day)	50 to 60 db
Quiet Residential	70 to 80 db
Noisy Commercial	85 to 95 db
Heavy Traffic	90 to 100 db

As a typical example of the effects of noise-level attenuation on detection, consider a vehicl[illegible] traveling towards a coast on a c[illegible]m day. The noise level at the vehicle is taken as [illegible]0 db, and [illegible]he vehicle is turbine powered.

The over-all noise level at various distances from the vehicle then becomes, with no atmospheric attenuation:

100 yards	90 db
1000 yards	70 db
10,000 yards	50 db

With a gas turbine engine, the frequency band that contains the highest noise level is the region of 700 to 1300 cycles per second — say 1000 cycles per second. So very roughly, the over-all noise level at the various distances may now become, with atmospheric attenuation

100 yards	90 db
1000 yards	67 db
10,000 yards	19 db

and with an ambient noise level at the coast of 50 db, the distance at which detection is possible will be about 2500 yards.

This examination of the noise signature problem serves to highlight the importance of this area. The results obtained represent orders of magnitude only; much work remains to be done before ALVs can be effectively designed with a minimum noise signature.

(2) Dust and Spray

Dust, spray, sand and snow clouds all contribute to a lack of operational security by assisting the enemy to detect the presence of activity.

GEMs, by virtue of their basic lift mechanism, disturb the surface over which they are operating. The air jets that retain the lifting cusion blow out along the ground with initial velocities that depend on the cushion pressure, and can vary from 100 feet per second to 300 feet per second, over a range of vehicles.

These air jets entrain surface particles and project them away from the vehicle and upwards. The smaller particles are then carried by surface winds, while the larger ones fall back to the surface.

At zero forward speed, this entrainment occurs all around the vehicle, and creates a curtain of particles that hamper the operation of the vehicle and make the vehicle visible at increased ranges. The longer the vehicle hovers, the more particles are removed from the surface by the air curtain, until a "bucket" is formed in the surface which results in particles being projected more or less vertically. When this condition is reached, a maximum "signature" has been created.

At forward speeds the curtains and the entrained particles are deflected rearwards, and a reduced degree of entrainment occurs, since the relative velocity between surface and curtain has been reduced. Hence, at forward speed this spray or dust cloud is appreciably reduced in magnitude.

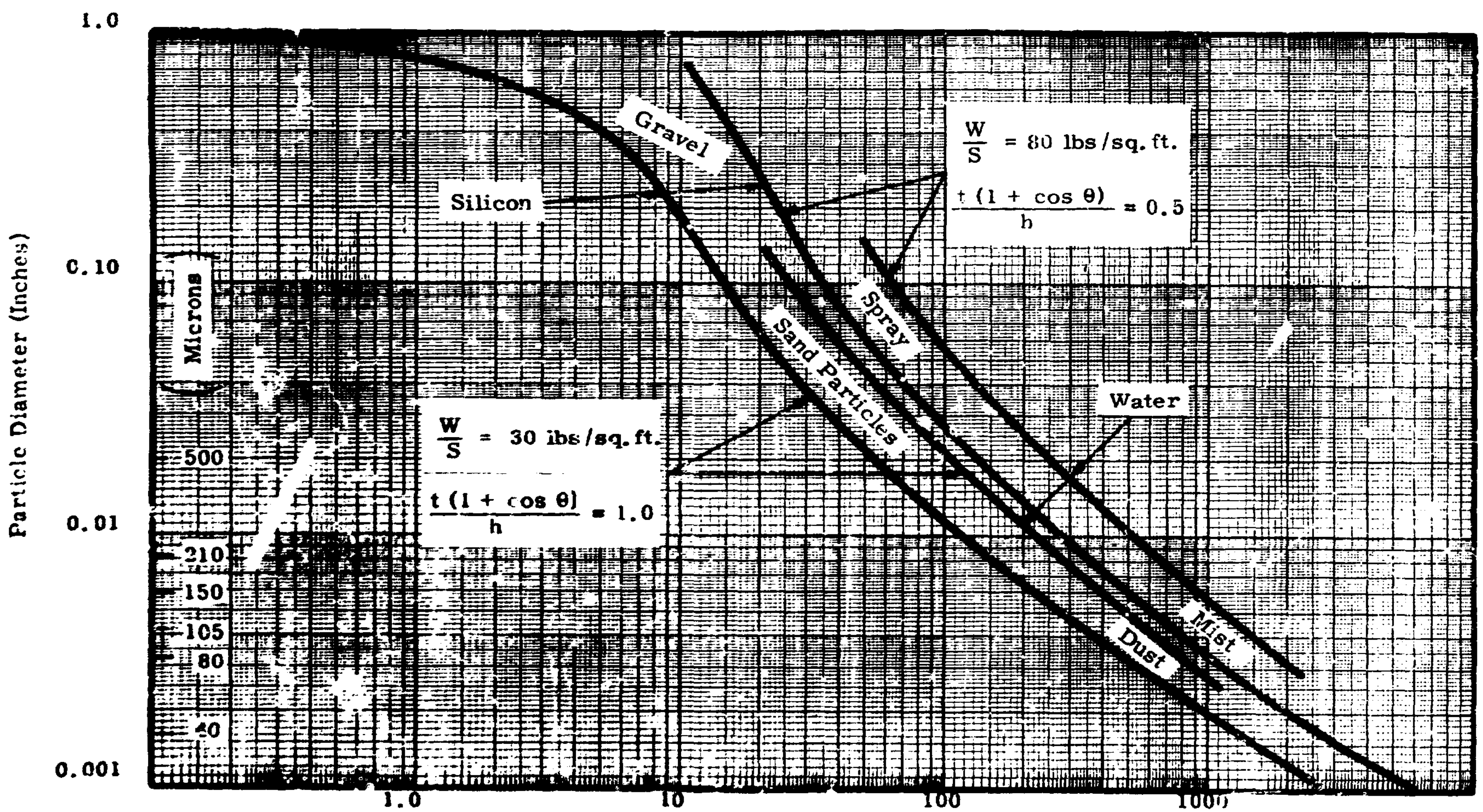
Current experience indicates that spray and dust can be expected to rise to heights approximately 15 to 20 times the operating height of the vehicle in hover, and that this will be maintained up to speeds on the order of [illegible]0 knots, although the crest of the cloud will move rearwards by about one vehicle length. Beyond these speeds, the cloud may be expected to reduce in size.

A very simple form of analysis serves to indicate the maximum heights and maximum radial distances to which particles could be carried by the jet curtain air.

On the assumption that prolonged hovering will produce essentially a vertical projection of the jet curtain air, and that particles will only rise in this air stream as long as the stream velocity is greater than the terminal velocity of the particle, Figure 15 illustrates the orders of magnitude that might conceivably arise, for silicon type particles (sand) and for water particles (spray). (29, 46)

Figure 15

Vertical Projection of Silicon and Water Particles



It is seen that quite appreciable heights are predicted for the very small particles, but these are open to considerable doubt, due in part to the fact that the deflected air stream will undoubtedly dissipate much more rapidly than has been assumed, and due also to the necessary extrapolation of the data (46) on decay of dynamic pressure in a jet exiting into free air. In addition to this, particle sizes below about 100 microns possess terminal velocities that are comparable with the random air currents in the atmosphere and would more than likely be dissipated long before reaching their theoretical zenith.

This discussion serves to emphasize the need for a more thorough investigation into the flow fields and entrainment mechanisms involved in the generation of dust and spray by GEMs.

Experience with the Curtis-Wright Air Car provides an approximate correlation with part of this analysis. Spray heights of the order of 10 to 12 feet were observed in hover, at hover heights of the order of 6 to 12 inches giving a ratio of spray height to hover height of 20 to 10, which from the chart, for low planform loading vehicles, corresponds to water particles in the region of .10 to .30 inch in diameter. It is not known whether this experience was on the pure plenum Air Car,

or on the vehicle with the annular air modification. If this were for the pure plenum vehicle, lower heights than those calculated would be anticipated, since the entraining air stream should be less intense, and less outward than for an annular jet machine.

A similar analysis, Figures 16 and 17, shows the lateral spread of particles, in which it has been considered that a deflected jet angle of 45° will carry particles the furthest distance, by entraining them in the jet until the vertical velocity component in the jet is equal to the particle terminal velocity. The particle is then assumed to act as a projectile with an initial horizontal velocity equal to its terminal velocity. Again the results show values that are not unreasonable, and serve to indicate the order of change in spread as hover height or vehicle platform loading are increased.

(3) Camouflage Techniques

At the very least, steps must be taken to provide a non-reflective finish to the machine, coupled with a carefully chosen coloring scheme to break up the natural contours of the machine. These techniques were well established in World War II and in Korea.

Figure 16

Horizontal Projection of Silicon Particles

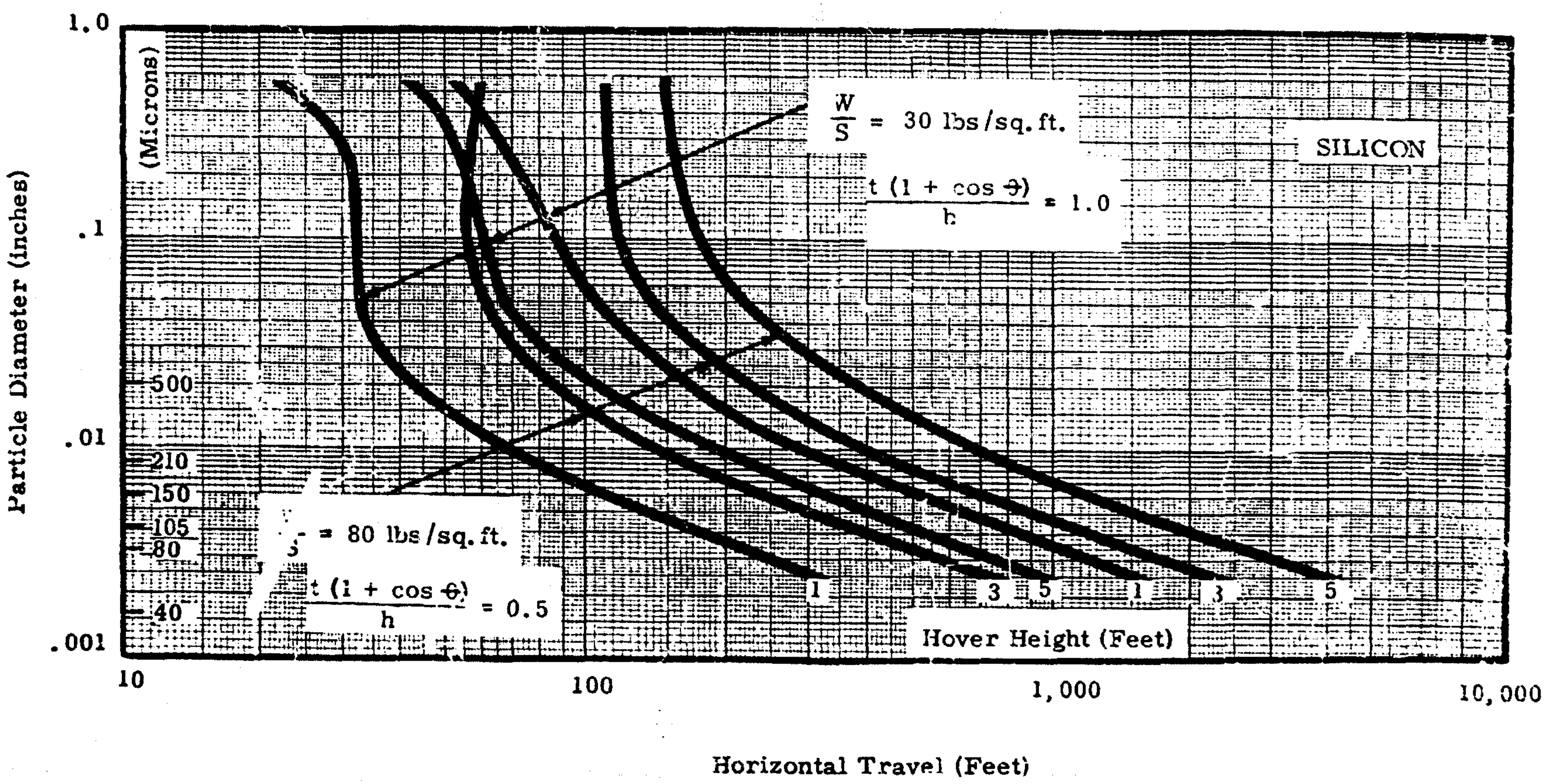
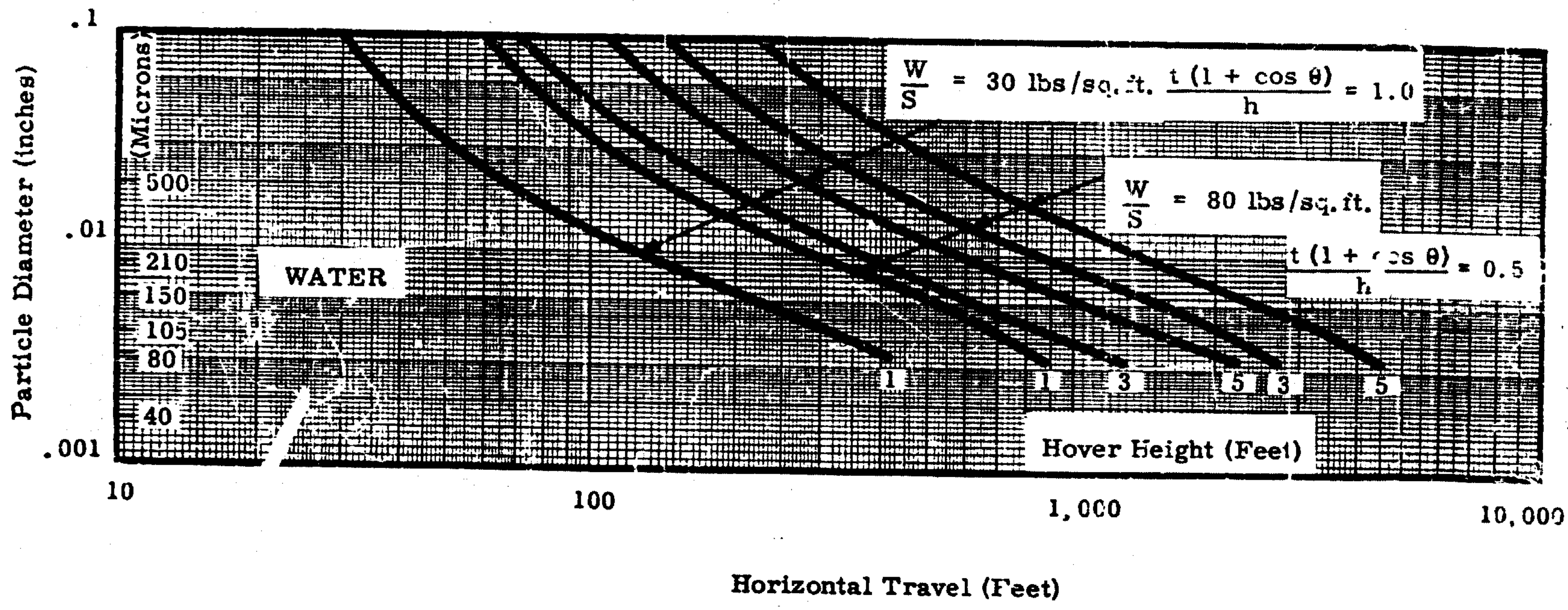


Figure 17

Hor zontal Projection of Water Particles



(4) Radar Reflectivity

The radar equation is

$$R^4 = K \frac{P_t\ G_t\ G_R\ \ {}^2\ \ A_t}{P_R}$$

R	is maximum range.
P_t	is transmitter mean power.
G_t	is transmitter aerial gain.
G_R	is receiver aerial gain.
λ	is wavelength.
α	is function of atmospheric attentuation.
A_t	is target echoing area - a measure of the fraction of incident radiation that is reflected back to the radar receiver.
P_R	is the minimum detectable signal.
K	is the constant of proportionality.

The only factor over which a GEM designer has control, then, is A_t. The main factors that affect A_t and the returned signal are the smoothness and angular position of the reflecting surface relative to the incident beam, causing fluctuations of the echo as the target approaches the radar.

Note that for modern jet aircraft, the air intakes are a major source of radar echo; interference occurs between the echoes from several intakes or similar portions of the vehicle causing its apparent mean position to change rapidly and inconsistently. This is useful in

confusing homing weapons possessing radar homing devices. However, the presence of strong signals of this type means that detection is easier, and if the fluctuating nature of the return is recognized, radar homing devices could be discarded in selecting a retaliatory weapon.

It would seem that to minimize radar reflectivity in the direction of motion, the frontal aspect of a GEM should be sharp with no planar areas or intersections located normal to the direction of motion. If this can be achieved, the radar pulse will be reflected in specular fashion away from its initial path, and no radar signal will be evident from the GEM. Note, that where dimensions on the vehicle are of the order of the radar wavelength, diffraction occurs, which may give rise to a return signal. This indicates the necessity to preserve a smooth external contour to the GEM, with the minimum of appendages, bolt heads and nuts, lap joints pointing forward, and so on. Several forms of coating are under development, that are at least partially effective in absorbing the radar signal at normal radar frequencies, and could be considered in this area.

It would seem reasonable to expect radar cross-sectional areas* of the order of 5-10 square feet to 50-100 square feet going from small personnel GEMs to large over-water transport GEMs of the order of 100 tons gross weight.(67) It should be emphasized that this depends very much on configuration, shaping, aspect, and in addition on the presence of rotating propellers that are similar to aircraft propellers. These modulate the radar return and may produce a characteristic signal. Possibly the use of ducted or shrouded propellers will minimize this effect, since the increment in the return signal in the case of aircraft propellers lies largely in the propeller plane; propulsion means other than air propellers show to considerable advantage from this point of view.

(5) Infrared Emanation

The ICA requirements for Infrared radiation are that the IR levels must not exceed:

---

* Based on small freighter, small surfaced submarine	1.5 square feet
medium freighter	80 square feet
large freighter	160 square feet

1. 10^{-9} watts per square centimeter at 100 yards in wavelength ranges from 3.0 to 5.5 microns, and from 7.0 to 14.0 microns.

2. 10^{-10} watts per square centimeter at 100 yards in wavelength ranges from 1.8 to 2.7 microns.

From a study of the temperature distribution of typical engines likely to be utilized for Ground Effect Machines, it would appear that the maximum IR radiation at the engines, if completely exposed, will be approximately 60 watts per square centimeter.

This value will in general be less at source, due to lower operating temperatures than the maximum considered, and will also be insulated by the surrounding structural material necessary to the vehicles' design. Further reduction in intensity occurs first as a direct result of the special spreading of the IR radiation, and secondly as a result of atmospheric absorption.

Since the GEM engines will have operating temperatures similar to those for military aircraft, it is anticipated that the GEM can be designed to meet the same IR requirements, probably with greater ease, since the presence of the ground and its allied obstructions and atmosphere will inhibit the passage of IR radiation more than for aircraft.

(6) Vulnerability

A preliminary assessment of GEM vulnerability can be made by qualitative comparison with other vehicles performing similar functions under the same conditions of retaliatory firepower.

Vehicles that will perform the same function at least in part, as a GEM, are landing ships and trucks.

Vulnerability of these vehicles is first related to size and speed. The larger a vehicle is, the more likely it is that a hit may be scored. The slower it travels, the more likely it is that a hit may be scored.

As qualifiers to this are (1) the degree of damage or casualties that will be incurred by a hit (this is a function of the built-in protection of the vehicle); (2) the profile of the vehicle in relation to the type of attack; (3) the maneuverability of the vehicle in avoiding attack or degrading aiming accuracy.

GEMs and ships of equal size (gross weight) can be compared.

The GEM profile will be lower than a corresponding ship, probably shorter but somewhat wider. This provides a less definitive target for a shore-based defender, but a larger target for aircraft.

The GEM speed will be 3 to 5 times that of a similar ship, and it will be capable of faster maneuvers than a ship. This will make it a harder target for both ground and air defending equipment.

It is possible and desirable to configure a GEM such that the lift cushion pressure can be maintained in the event of damage to part of the lift structure. Multiple power plants with modular construction will go a long way to providing this capability. With this approach, the GEM will not be as vulnerable as a similar ship to a direct hit on a power plant; such a hit on a ship will also result in severe damage to the hull and may sink the ship, whereas the GEM can continue. This requires that the lift system be guarded by some degree of armor, in turn providing an additional level of protection to the personnel and cargo in the event of fan-blade failure.

In the event of failure of the lift system, due to duct penetration or severe power-plant damage, an auxiliary power source can still provide water mobility if adequate flotation capability is designed into the GEM structure at the start.

In addition, the GEM is not vulnerable to torpedo attack.

Similarly, the GEM and corresponding truck may be compared:

The profile of GEM and truck will be about the same if the GEM has to carry the truck load and operate on truck routes, so there will be little difference in vulnerability in this respect.

When operating over areas where a truck operation is marginal the GEM speed and maneuverability will be a distinct advantage and will reduce its vulnerability. However, when operating over truck routes, the GEM speed will be limited to truck speeds and no difference in vulnerability will be evident.

Penetration of a truck tire is a severe disability, and will create a greater loss of control than penetration of the duct of a properly designed GEM.

The power unit and personnel compartments are equally vulnerable for the two vehicles and require the same order of protection.

Note that this comparison is a little different if the vehicle choice is different -- if a large GEM is chosen to replace several small ships and/or trucks, then although the GEM will operate faster than the ships

or trucks, thus reducing vulnerability, its size will increase its vulnerability. In given conditions of fire, the GEM may be destroyed whereas a number of smaller craft may still get through to the beach. This is an argument in favor of large numbers of small GEMs, under some circumstances.

(7) <u>Damage Protection</u>

This consideration is of damage created by enemy action, due to:

- blast,
- shrapnel,
- mines,
- bombs,
- shells,
- fire.

The areas of interest on a GEM are:

1. the power plant,
2. the lift-producing system,
3. the propulsion system,
4. the crew and cargo areas,
5. the control surfaces.

Of these areas, the lift-producing system requires particular attention. The other areas can be designed with normal military vehicle protection in mind.

As far as the lift system is concerned, damage protection is needed in particular for the lift fan and gearing, and for the ducting associated with producing the sustaining cushion.

(8) Field Repairs

Field repairs for an operational GEM should be as straightforward as those for the Army's light aircraft and jeeps, consisting primarily of replaceable parts, with the minimum of actual repair work to be done. Modular construction methods in the design of the vehicle will greatly facilitate this aspect.

(9) GEM Operation in Mine Fields

The range of footprint pressure experienced with GEMS is about 30 lb/sq. ft. to 80 lb/sq. ft.; the likely acoustic over-all sound pressure levels close to the machine are in the order of 110 db to db relative to .0002 dynes/cm^2; other features of GEMs may also be important for initiation of mine explosions, such as the "magnetic anomaly" signature (local distortion of the earth's magnetic field), of the vehicle.

Most sea mines are designed to explode when subjected to the magnetic, acoustic or pressure fields of "worthwhile" targets, namely vessels of 3000-tons displacement or greater. It is very unlikely that Ground Effect Machines, as they are now envisioned, will be built approaching this size. In addition to this, the effect of a mine is dependent largely upon transmission of pressure waves through the water to reach the hull of the target ship. When the pressure wave reaches the surface, most of the energy is dissipated and the effect lessened appreciably. Since a GEM will operate clear of the water surface, the most lethal characteristic of sea mines cannot be utilized and the GEM will be subject to the secondary characteristic comprising a column of water thrown out of the water. This may cause some damage on impact with the GEM.

Land mines are tailored to react to specific vehicles that are worthwhile targets. The size of charge and the sensitivity of the detonating mechanism are dependent on the desired target. Antipersonnel mines are small and very sensitive, whereas antitank mines are large and can be walked on without detonation. These mines are sensitive to footprint pressures and magnetic anomalies associated with the desired vehicles. Since GEM footprint pressures of the order of 30 to 80

lb/sq. ft. are 1/15 to 1/150 of the footprint pressures of conventional land vehicles, and since the GEM structure is largely aluminum compared to the predominantly steel construction of a tank or truck, passage of a GEM would be most unlikely to detonate conventional mines. If an explosion should occur near a GEM, damage to the annular jet and cushion area could result, but with proper design, the vehicle should still be able to continue its mission before field repairs are necessary.

(10) Nuclear Explosions

The combat missions that require operation in a nuclear explosion environment present a number of interesting and potentially hazardous problems, to operating personnel and vehicle alike.

1. Radiation

The major result of GEM operation in a radiation environment is the increased local density of radio-active particles surrounding the GEM while in hover or at low forward speeds, due to the re-ingestion phenomena. This will cause a continual recirculation of radio-active particles, intensifying the radio-active field surrounding the vehicle (a local "van Allen" belt) hence affecting the personnel.

The same increase in intensity means that the components comprising the GEM lift system will be subjected to a greater radiation intensity than would normally be the case with other vehicles, while hovering or at low forward speeds. Those materials that are subject to deterioration in a radiation environment must be chosen with this in mind in the design stage, or subjected to more frequent inspection in operation.

2. Effect of Blast and Temperatures in a Nuclear Combat Situation

Effect of nuclear blast depends obviously on the magnitude of the explosion and the distance from the explosion. The first observation is that since the GEM is essentially frictionless in its motion over the surface, the pressure wave of a nuclear blast will cause an impulsive force to act on the GEM which will send it skimming over the surface in the direction of travel of the blast wave. Secondly, the presence of an approximate aerodynamic shape to the GEM and some degree of directional stability will cause the GEM to face into the blast wave and develop high aerodynamic forces which will pitch the vehicle nose up or down (depending on the basic stability and control

of the GEM and the trimmed condition) and probably contact the ground and become completely uncontrolled. The initial positive pressure wave is followed by a negative pressure wave of similar magnitude which produces relative velocities at the GEM in the opposite direction to further aggravate the situation.

The positive and negative pressure magnitudes in the blast wave may also create intolerable conditions for the operating personnel in the vehicle, unless the vehicle is sealed and stressed to prevent rapid pressure fluctuations in the cabin. This is common to all manned vehicles in this situation.

Temperature and flash effects on the vehicle are dependent on the surface finish and surface material of the vehicle; the effects on personnel are largely dependent on whether the cabin transparencies would permit direct radiation into the cabin. Transparent materials have recently been developed that are sensitive to light intensity in such a way that they become opaque to radiation in the visual and infrared frequency ranges in fractions of a second. These may alleviate the transient effects of flash and temperatures.

(11) Loadability of GEMs in Marine and Amphibious Operations

There are distinct limitations on the sea conditions in which a cargo ship can successfully and safely unload its cargo offshore, arising from the inherent pitch, heave and roll characteristics of cargo ships in different sea states, and the inertia characteristics of cargo pallets suspended from unloading hoists and cranes.

Unloading operations are fairly safe up to wave heights of three to four feet and become hazardous above sea states of six to eight feet. This means that there is no advantage in designing GEMs, for this type of operation, that can perform their function in sea states greater than 4-1/2 to 6 feet, until the stability characteristics of cargo ships can be radically improved. A possible alternative is to consider a loading and unloading operation underway at sea, if this operating condition results in appreciable damping of the ship motion. This, however, requires very careful investigation as to its feasibility particularly in terms of adequate means for station keeping between ship and GEM.

4. SUMMARY OF INDUCED AND COMBAT ENVIRONMENTS.

The elements of induced and combat environments discussed in this chapter are summarized in Tables 18 and 19 following this page.

Table 18
Induced Environments
Summary Data

Noise

Maximum Overall Noise Level, Relative to .0002 Millibar				
Location	Acceptable (Air Force)	Experienced	Expected	Special Equipment Needed
Inside Vehicle	113	90 to 120	80 to 95	Ear protection for continuous use. Telephony for adequate operational functioning.
Close to Outside of Vehicle	113	90 to 120	90 to 120	
	See Combat Environment Summary on Noise (Table 19)			

Table 18 (Cont.)
Vibrations

Acceptable limits, for Crew Stations		Experience to date
Frequency, (cycles/sec.)	Amplitude (in.)	No indications that these values will be exceeded. No vibration problems so far.
1	$.02 < h < 2$	
10	$.0002 < h < .02$	
100	$.00002 < h < .0005$	

Temperatures (maximum values)

Engine	Combustion Chamber Area	Exhaust Area
Piston	240° C to 200° C	1000° C to 600° C
Jet	200° C to 250° C	800° C to 850° C

Exhaust Gases

Engine	Inert	Toxic	Water and Oxygen
Piston	77 per cent	6 to 18 per cent	17 to 5 per cent
Jet	77 per cent	1.5 to 4.8 per cent	21.5 to 18.4 per cent

Table 18 (Cont.)
Static Electricity

Typical Accumulated Charge (volts)	Stored Energy Levels (millijoules)	Energy Level for Spark Ignition of JP-4 (millijoules)
300 to 400	2×10^{-4} to 2×10^{-2}	0.2

Effect on Personnel Bridging Gap
Initial current level--lethal Drops below lethal level within 2 millionths of a sec.

Solution to all Problems of Static Charge
A trailing ground contracting conductor, and good vehicle bonding throughout.

Visibility Reduction

Due to:	Comments
Configuration	No worse than a ship, better than an aircraft
Night and Bad Weather	Usual solutions applicable
Surface Disturbance	
1. Forward Speed	No problem forward, upwards, or sideways. Some obstruction by surface material towards rear.
2. Hover	Severe loss of visibility. No major problem, as GEM basically stable and can move from hover location under full contact, to regain visibility.

Table 18 (Cont.)
Acceleration and Shock

Accelerations at CG.	
Longitudinal	+ .2g. to - .5g
Lateral	± .4g
Vertical (approx.)	± .3g to ± .4g

Shock

Operating height = .02 (vehicle length)

Wave length = 2.0 x (vehicle length)

"Sinusoidal" wave height = 1.5 x (operating height)

Equivalent "Random Sea" wave height = 3.0 x (operating height)

Operating Conditions	Normal Operating Speed	Twice Normal Operating Speed
At Bow - no immersion	9.0 to 12.0 g	18 to 20 g
with immersion	6.0 to 8.0 g	12 to 15 g
At Center of Gravity	3.0 to 6.0 g	6 to 12 g

Table 18 (Cont.)

Ingestion

Material	Concentrations and Particle Sizes	Effect on Lift System & Propulsion	Engines
Dirt and Sand	0-80μ 40-105μ, 105-200μ. 0.01 gms/cu. ft.	Rotor blade and intake erosion, with loss in efficiency	Compressor blade erosion, up to 10 per cent power loss, reduction of surge margin, high turbine inlet temperatures
Large Particles & Objects	From 200μ through 1/4 diam. bolt to 4 lb. birds	Blade and intake damage, followed by blade failure	Nicked, dented, twisted compressor blades, damaged inlet screen facing. Stripped compressor stages, complete failure. Subsequent failure due to damage.
Ice	1/2" to 3" diam. hailstones, shaved ice	Intake damage, little or no blade damage	Damaged intake screens. No compressor damage, occasional flame-out
Salt Water	2 to 500μ >10 c.c./min./engine	Salt incrustation with loss in power	Slight erosion, salt build up, power loss, SFC rise
	"Solid" or "green"	Destruction of fan blading, bending of prop blading	Flame out, inlet damage, compressor damage

Table 18 (Cont.)
Ingestion

Material	Concentrations and Particle Sizes	Effect on Lift System & Propulsion	Engines
Dirt and Sand	0-80μ 40-105μ, 105-200μ, 0.01 gms/cu. ft.	Rotor blade and intake erosion, with loss in efficiency	Compressor blade erosion, up to 10 per cent power loss, reduction of surge margin, high turbine inlet temperatures
Large Particles & Objects	From 200μ through 1/4 diam. bolt to 4 lb. birds	Blade and intake damage, followed by blade failure	Nicked, dented, twisted compressor blades, damaged inlet screen facing. Stripped compressor stages, complete failure. Subsequent failure due to damage.
Ice	1/2" to 3" diam. hailstones, shaved ice	Intake damage, little or no blade damage	Damaged intake screens. No compressor damage, occasional flame-out
Salt Water	5 to 500μ >10 c.c./min./engine	Salt incrustation with loss in power	Slight erosion, salt build up, power loss, SFC rise
	"Solid" or "green"	Destruction of fan blading, bending of prop blading	Flame out, inlet damage, compressor damage

Table 18 (Cont.)
Ingestion (Cont.)

Methods for Combating Effects	GEM Industry Comments
Deflectors Coatings	No indication of major problems as yet.
Debris Guards	
Debris Guards	
Deflectors, Coatings, Washdown, Inhibitors.	Indications of appreciable salt build-up in lift system intake and ducting.

Snow and Ice Accumulation

Type	Characteristic	Problem	Severity	Solution
1.	Accumulation on static vehicle in snow storm	Removal	As for existing transportation vehicles and aircraft	Standard de-icing equipment, snow removal equipment
2.	Icing at forward speeds in snow storms	"	"	"
3.	Operation over water in subfreezing temperatures	" "	More severe than (1) or (2)	More sophisticated equipment, or new approaches.

Table 19
Combat Environments
Summary Data

Noise	
Major sound pressure levels at source.	
Engines (turbine and piston)	$(12 \log_e (HP) + 95) \pm 10$ db
Fans 4 to 6 blade, 50 to 150 HP per fan, HP speed $<$ 1100 fps.	130 to 150 db
Over-all sound pressure levels, approximately 1 yard from complete vehicle.	
In line with intakes (propulsion, lift, etc.)	110 to 130 db
In line with exhaust	110 to 130 db
Elsewhere	90 to 110 db
Approximate spherical spreading attenuation with distance from vehicle.	
At 100 yds.	- 40 db
1000 yds.	- 60 db
10,000 yds.	- 80 db
Ambient noise levels	
Jungle	40 to 50 db
Coast	50 to 60 db
Quiet residential	70 to 80 db
Noisy commercial	85 to 95 db
Heavy traffic	90 to 100 db

Table 15 (Cont.)

Noise				
Approximate atmospheric attenuation with distance	Frequency (cycles per second)			
	10	100	1000	10,000
100 yds.	$.66 \times 10^{-3}$	3.78×10^{-3}	312.7×10^{-3}	31.2
1000 yds.	6.9×10^{-3}	37.8×10^{-3}	3127×10^{-3}	312
10,000 yds.	69×10^{-3}	378×10^{-3}	$31,270 \times 10^{-3}$	3120

Sand and Dust

Particle Size (inches diameter)	Lightly loaded GEM 30 lbs/sq. foot.		Heavily loaded GEM 80 lbs/sq. foot.	
	Max. height	Max. distance	Max. height	Max. distance
.005	300h	140h	600h	310h
.01	100h	70h	300h	150h
.050	25h	[illegible]-32h	60h	42-6[illegible]
.10	15h	27-32h	35h	34-56h
.50	4h	11-22h	15h	30-60h

Note: h = Vehicle operating height - feet

Spray and Mist

Particle Size (inches diameter)	Lightly loaded GEM 30 lbs/sq. foot.		Heavily loaded GEM 80 lbs/sq. foot.	
	Max. height	Max. distance	Max. height	Max. distance
.005	500h	[illegible]	[illegible]	600h
.010	250h	120h	550h	270h
.050	50h	30-38h	100h	68-80h
.10	25h	21-32h	60h	44-60h

Note: h = Vehicle operating height - feet

Table 19 (Cont.)

Radar Reflectivity

Likely cross-sections for GEMs	
Vehicle sizes	Radar cross-section (sq. ft.)
5 ton	5-10
100 ton	50-100

Requirements will be that vehicle radar cross-section be minimized. This is achieved by careful attention to configuration details, shaping, aspect; by shrouding propellers as much as possible; by utilizing coating media capable of high absorption at radar frequencies.

Infrared Emanation

IR radiation	- Less than 10^{-9} watts/sq. cm. at 100 yds. in wavelength range 3 to 14 microns and less than 10^{-10} watts per sq. cm. at 100 yds. in wavelength range between 1.8 and 2.7 microns.

Typical requirements are those for Light Observation Aircraft. Maximum likely radiation intensity at vehicle is 60 watts/sq. cm. at exhaust or jet pipe - rapidly reduced and dispersed by insulation, structure and atmosphere.

Vulnerability (Relative)

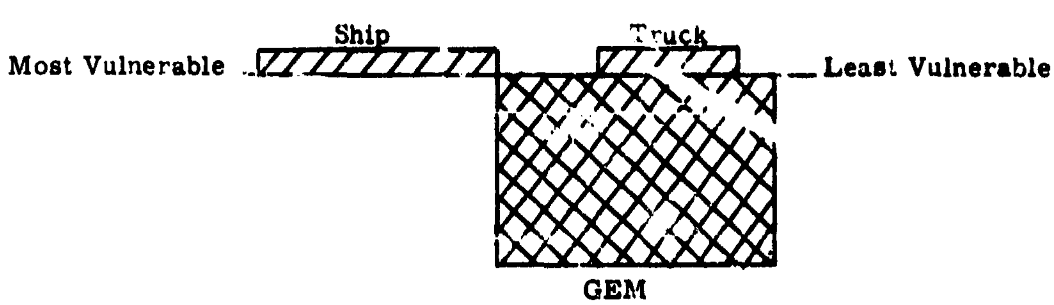


Table 19 (Cont.)

Damage Protection

Normal (aircraft or any vehicle) plus additional for lift system.

Field Repairs

Same as for current Army vehicles, facilitated by modular construction.

Mine Field Operations

Mine Type	GEM Characteristics	Effect of explosion on GEM
Pressure	30 lbs/sq. ft. to 80 lbs/sq. ft.	If explosion is under center of vehicle - instantaneous increase of cushion pressure, underside damaged by shrapnel - probably OK to continue. If explosion near edge - damage to annular jet ducting, reduction in efficient operation, damage to underside.
Acoustic	90 db → 100 db	
Magnetic	———	

Table 19 (Cont.)

Nuclear Environment

Environment	Effect on personnel *	Vehicle *
Radiation	In hover - Intensified radioactive field--more protection required. At forward speed - As for other vehicles of comparable speed.	In hover - As for personnel--more careful choice of materials or more frequent inspections. At forward speed - As for personnel.
Blast pressure wave	Severe pressure fluctuations inside vehicle, unless adequate sealing and strength designed into cabin.	Uncontrollable vehicle motions if near explosion, may result in complete destruction of vehicle.
Temperature and flash	Skin burns, blindness, unless protected from high burst intensities.	Flash--little effect. Temperatures--engine stalling, fuel fires.

* These are predicated on vehicle being near enough to explosion for the quoted effects to occur.

Loadability at Sea

GEM limited to design operating heights of 4.5 to 6 feet, until safe unloading capabilities of cargo ships are extended to greater sea states.

IV. EFFECTS OF SIZE AND OPERATIONAL UTILIZATION ON THE SELECTION OF A MILITARY GROUND EFFECT MACHINE

1. INTRODUCTION

The previous three chapters have developed in detail the environmental conditions throughout the world with which militarily-acceptable Ground Effect Machines will have to be compatible. Fifteen classes of machines have been selected, five each for overland operations, amphibious operations, and marine operations, purely on the basis of the range of environmental conditions to be encountered, without regard to the practicability of the resulting machine.

This chapter will discuss the approximate levels of performance that would be typical of each class of vehicle, bearing in mind the environmental conditions. Based on this information, the discussion will then indicate which vehicles appear to possess the greatest relative merit, when considering vehicle effectiveness as a transport, vehicle utility on a world-wide basis, and vehicle vulnerability in a combat situation.

2. DEVELOPMENT OF PERFORMANCE PARAMETERS

The vehicle characteristics defined by the environmental studies are:

- length
- width
- normal operating height at cruise
- maximum hover height (jump capability)
- slope capability
- maximum surface wind for hover

These have been developed in Chapter II together with a determination of percentage utilization, and are listed in Tables 11, 13, and 15 following pages 237, 267 and 283, respectively, for all fifteen classes of vehicles.

The performance capabilities of each vehicle in all three classes have been assessed, using the following assumptions:

(1) Vehicle Geometry

- Rectangular planform
- Cushion area = 60 per cent of planform area

(2) Vehicle Lift System and Aerodynamic Characteristics

- Drag coefficient = .06 based on cushion area
- Operational (Lift/Drag) ratio = $1/2\left[\frac{\text{cushion area}}{\text{annular jet length} \times \text{operating height}}\right]$
- Stability requires an additional 15 per cent of lift horsepower

- Cushion pressure = 70 pounds per square foot
- Optimum jet discharge angles and nozzle widths
- Over-all efficiency of duct and fan system = 60 per cent

(3) Vehicle Power Installation

- Installed power can be distributed at will between lift and propulsion systems
- Maximum continuous power = 90 per cent of total installed power
- Over-all propulsion efficiency = 80 per cent
- Specific fuel consumption at maximum continuous power = 0.7 pounds per hour per brake horsepower

(4) Vehicle Weight Distribution

- Structure weight = 20 pounds per square foot of cushion area
- Installed power plant weight = 1.25 pounds per brake horsepower
- Equipment weight including crew = 10 per cent of maximum gross weight

The evaluation of vehicle performance has utilized simple thin-jet momentum curtain theory for lift. The

determination of propulsion power has included the effects of momentum drag. With the above assumptions, no attempt was made to optimize or refine any aspect of the vehicles.

The following performance parameters have been developed for each class of vehicle:

- Weight breakdown
- Total installed power required
- Speed capabilities at maximum power and 90 per cent of maximum power, and at normal operating height, and the average of normal operating height and maximum hover height
- Payload-range characteristics, with delivery times

These parameters are given in Figures 18, 19, 20, and 21 following this page.

3. VEHICLE EVALUATION -

As a result of the environmental studies and the performance analyses it is possible to make an approximate assessment of the relative merit of each of the five vehicles in the three categories.

The basic merit of each vehicle [illegible] in its capability as a transportation device. This may be exp[illegible]ssed by its

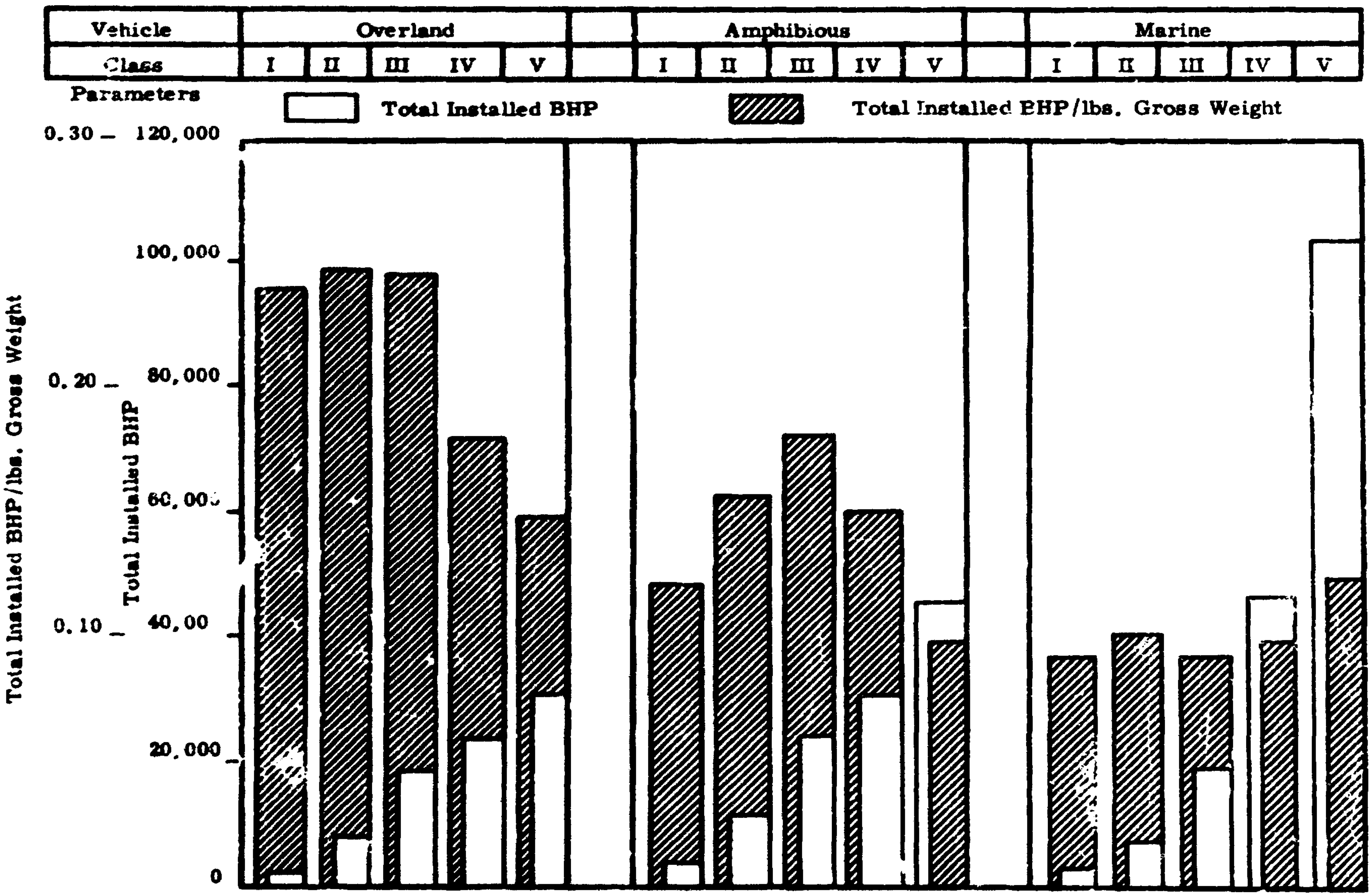
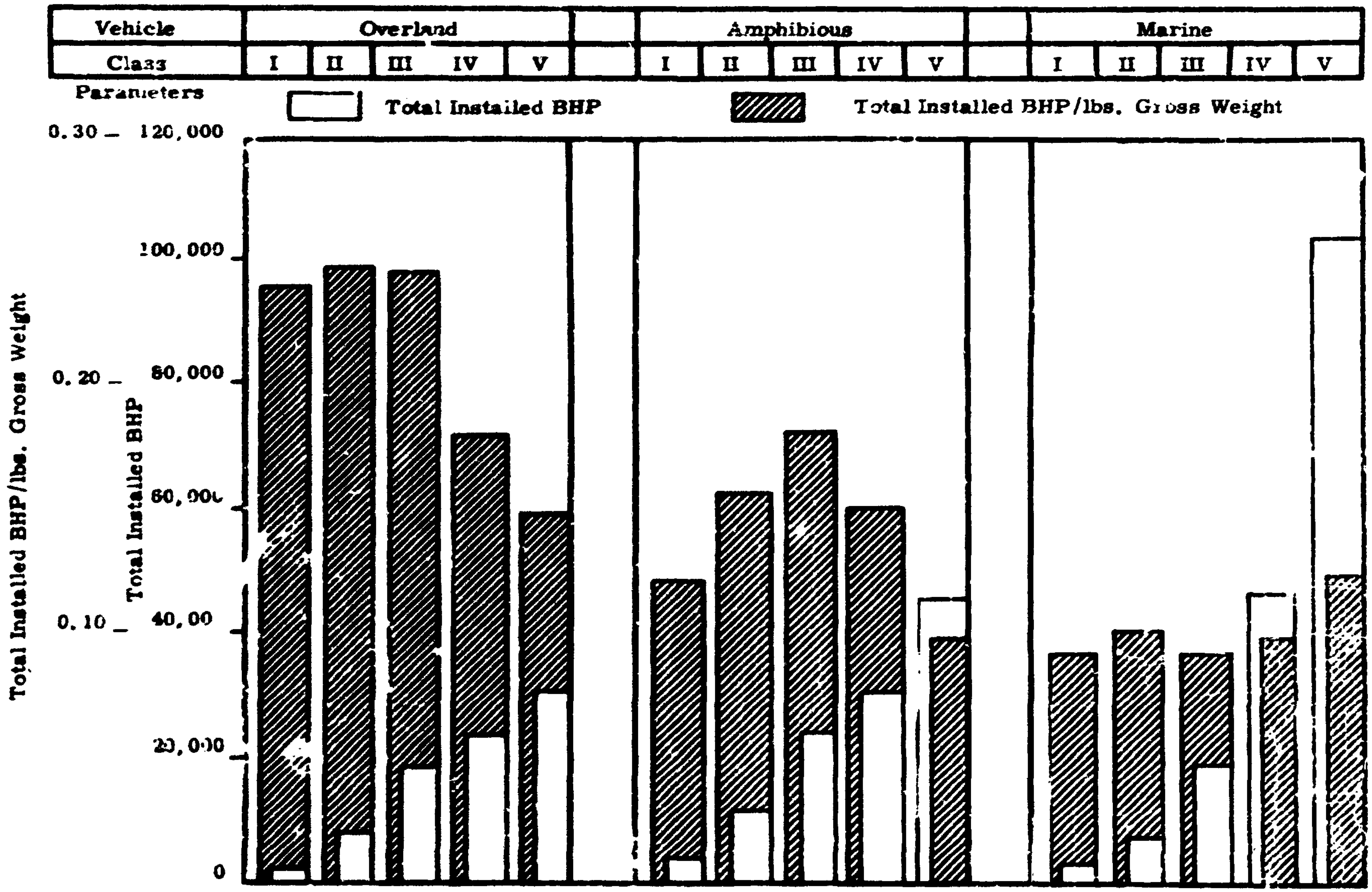


Figure 19. Power Requirements of GEM Classes



Vehicle
Overland
Amphibious
Marine
Class
I
II
III
IV
V
Parameters
Total Installed BHP
Total Installed BHP/lbs. Gross Weight
0.30
0.20
0.10
120,000
100,000
80,000
60,000
40,000
20,000
0
Total Installed BHP
Total Installed BHP/lbs. Gross Weight

Vehicle	Overland						Amphibious						Marine				
Class	I	II	III	IV	V		I	II	III	IV	V		I	II	III	IV	V

Note: "Reduced-speed Operating Height" is the average of normal operating height on cruise and maximum hover height at maximum power.

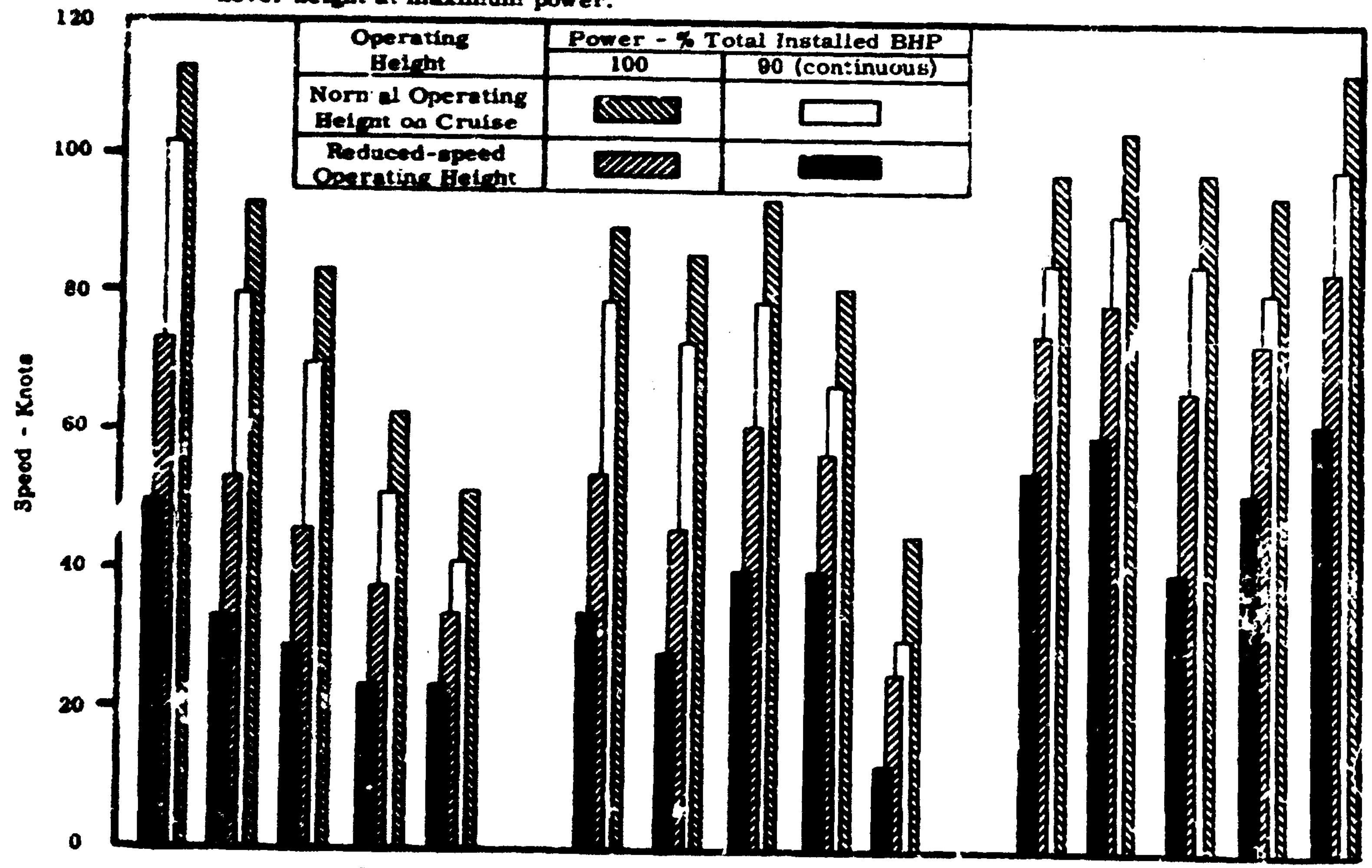
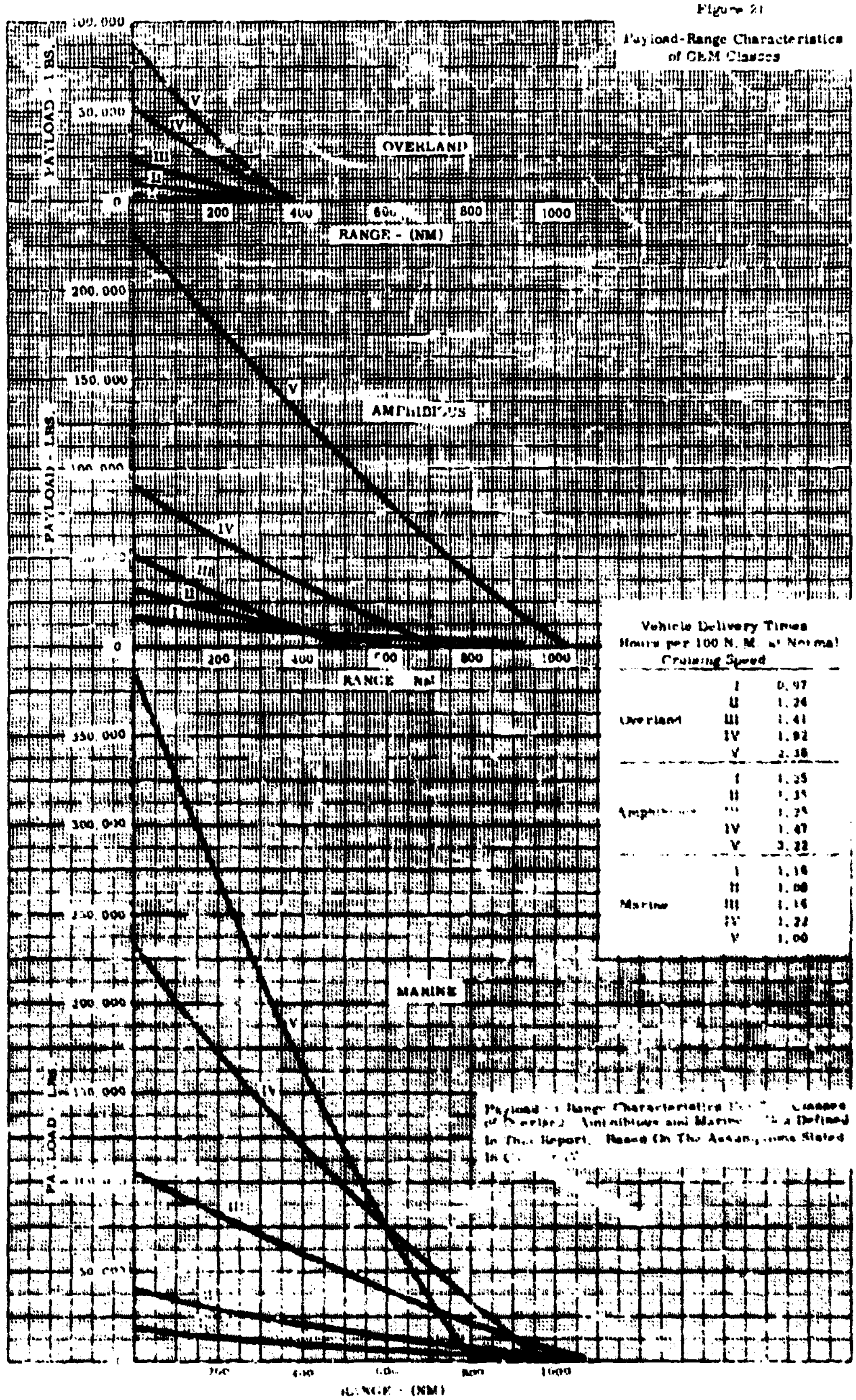


Figure 20 - Speed Capabilities of GEM Classes

Figure 21

Payload-Range Characteristics of GEM Classes



Vehicle Delivery Times
Hours per 100 N. M. at Normal Cruising Speed

Overland	I	0.97
	II	1.24
	III	1.41
	IV	1.92
	V	2.36
Amphibious	I	1.35
	II	1.39
	III	1.79
	IV	1.47
	V	3.22
Marine	I	1.16
	II	1.00
	III	1.16
	IV	1.22
	V	1.00

capacity for the work done by a given "income" of fuel. The parameter that describes this feature most adequately is

$$\left[\frac{\text{Payload x Range}}{\text{Fuel used}}\right]$$

and is in essence a measure of "useful work done per pound of fuel."

A comparison of all fifteen GEMs using this parameter would serve to indicate that some vehicles are better than others as transportation devices in the environment in which they have been classified. However, the fact that there are differences in world-wide usefulness for the different vehicles means that the transportation effectiveness must be considered together with the world-wide usefulness.

Further, since these are military machines, their vulnerability in a military situation is of great importance. If it is assumed that there are no radical differences in design philosophy from one vehicle to another, and that the same basic structural approach is used, then the degree of damage protection must be about the same. This eliminates the consideration of additional protection for the more vulnerable craft. An approximate measure of vulnerability, satisfactory for relative purposes, is to rank vulnerability proportional to $\left(\frac{\text{size}}{\text{speed}}\right)$: since the bigger the vehicle the easier it should be to hit, and the slower it goes the easier it should be to hit. This

approach provides a good means for measuring the relative vulnerability of a group of vehicles and has been used on the following pages.

(1) Overland Vehicles

Figure 22 shows the three parameters of transportation effectiveness, world-wide utility, and vulnerability, for the five classes of overland GEMs. First, as a result of factoring the effectiveness by the utility, it appears that Classes III and IV offer the highest potential on a world-wide basis. Then from consideration of vulnerability, Class III would seem to offer the best over-all capability.

(2) Amphibious Vehicles

As in the overland vehicle case, Figure 23 shows the three parameters. Effectiveness and utility combined indicate that Classes IV and V offer the best potential. With vulnerability then considered, Class IV emerges as the vehicle possessing the best over-all military capability in the amphibious field of operations.

(3) Marine Vehicles

For the marine vehicle, effectiveness and vulnerability are relatively easy to determine.

Figure 2[illegible]

Effectiveness, Vulnerability and Utility
of Overland GEM Classes

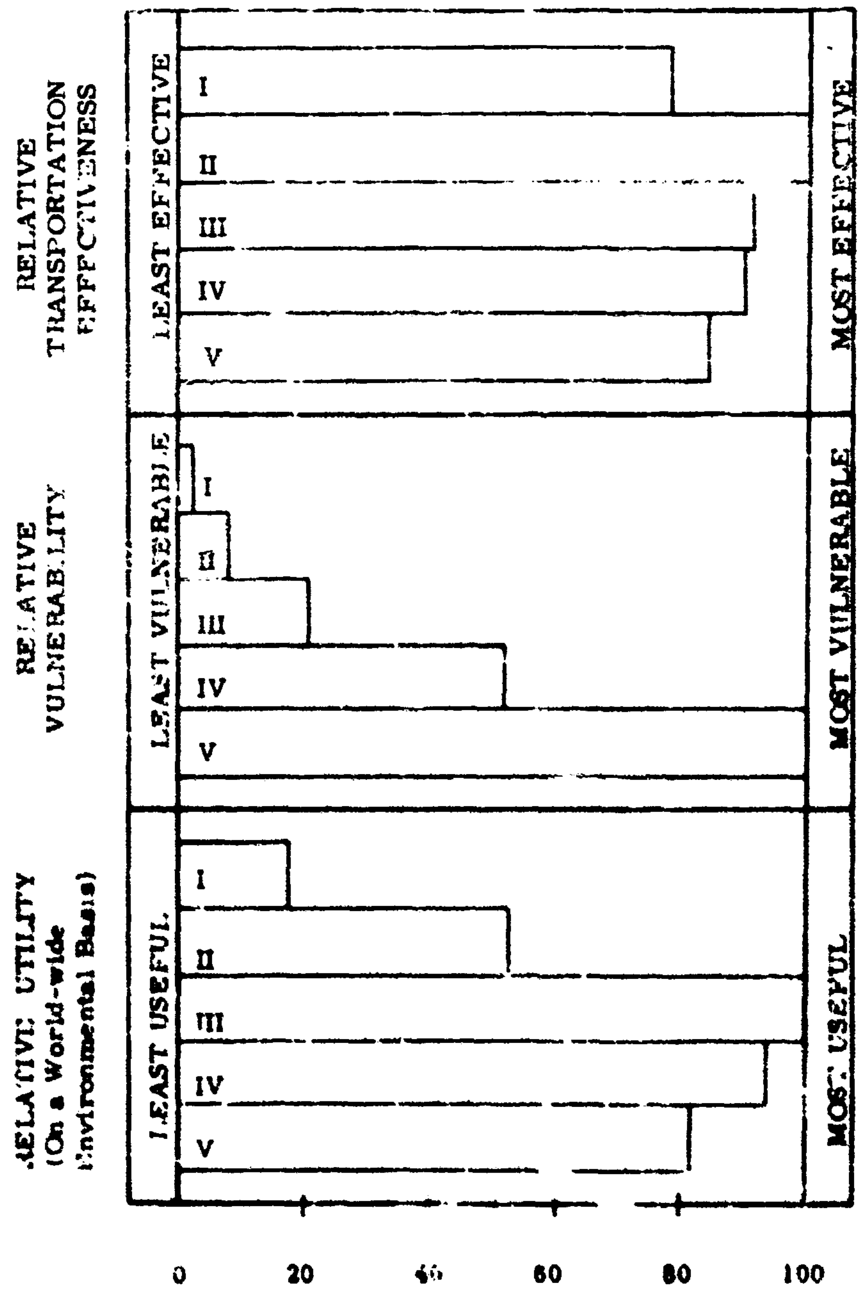
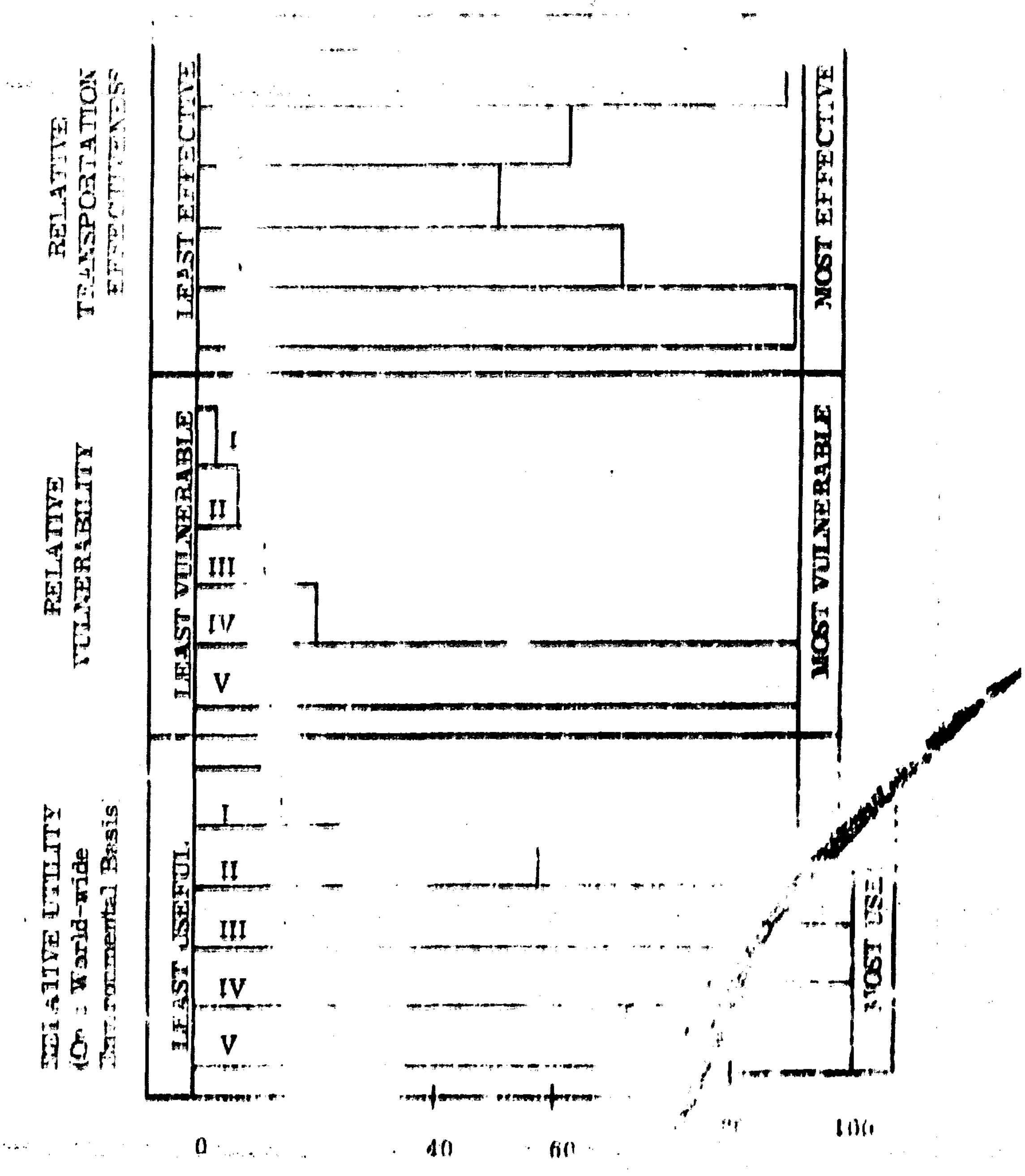


Figure 2[illegible]

[illegible]
[illegible]



RELATIVE TRANSPORTATION EFFECTIVENESS
LEAST EFFECTIVE
MOST EFFECTIVE
RELATIVE VULNERABILITY
LEAST VULNERABLE
MOST VULNERABLE
I
II
III
IV
V
RELATIVE UTILITY (On a World-wide Environmental Basis)
LEAST USEFUL
I
II
III
IV
V
0
40
60
100

These are shown in Figure [illegible] Util[illegible]
is much more complex when [illegible]idered [illegible]
basis, due to the dependen[illegible] [illegible] Figure [illegible]
on geographical location [illegible]
shows for the five classes [illegible]
in terms [illegible]
[illegible] percentage [illegible]tween [illegible]
limited to ocean areas [illegible] pos[illegible] the [illegible] of adequate
This limitation is [illegible] arctic [illegible]
wave data in th[illegible]y about five per cent of the total
eliminated [illegible] the open sea area. The data have been averaged between the summer and winter seasons with a loss in accuracy of approximately 5 per cent.

From consideration of effectiveness and utility, for operations in the open ocean, there appears to be little to choose from between Classes III, IV, and V. However, when vulnerability is considered, Class III appears to offer the greatest potential. For inland and coastal waterways, no clear decision can be made in favor of either Class I or II since they both possess the same effectiveness. Class II has a greater annual utilization due to its higher operating height, but Class I is less vulnerable in a combat situation.

Figure 24

Effectiveness, Vulnerability and Utility of Marine GEM Classes

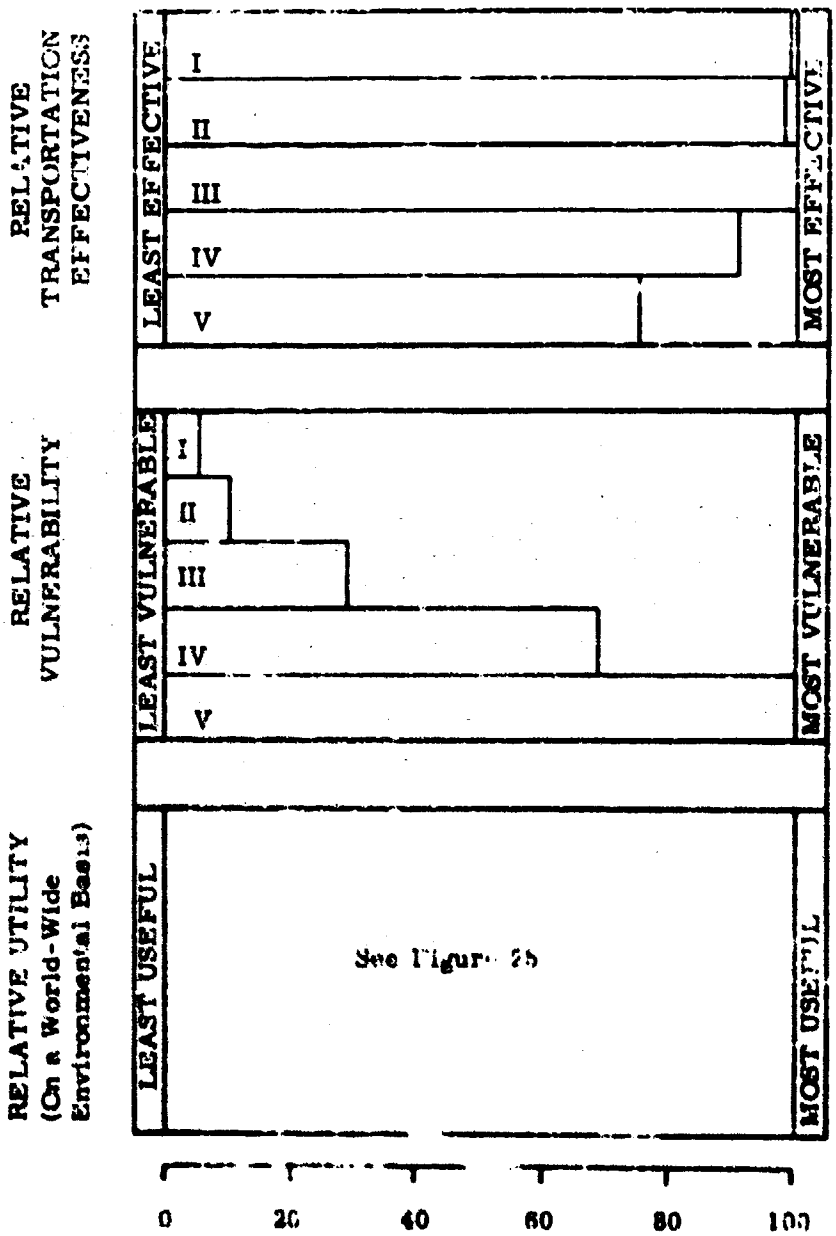
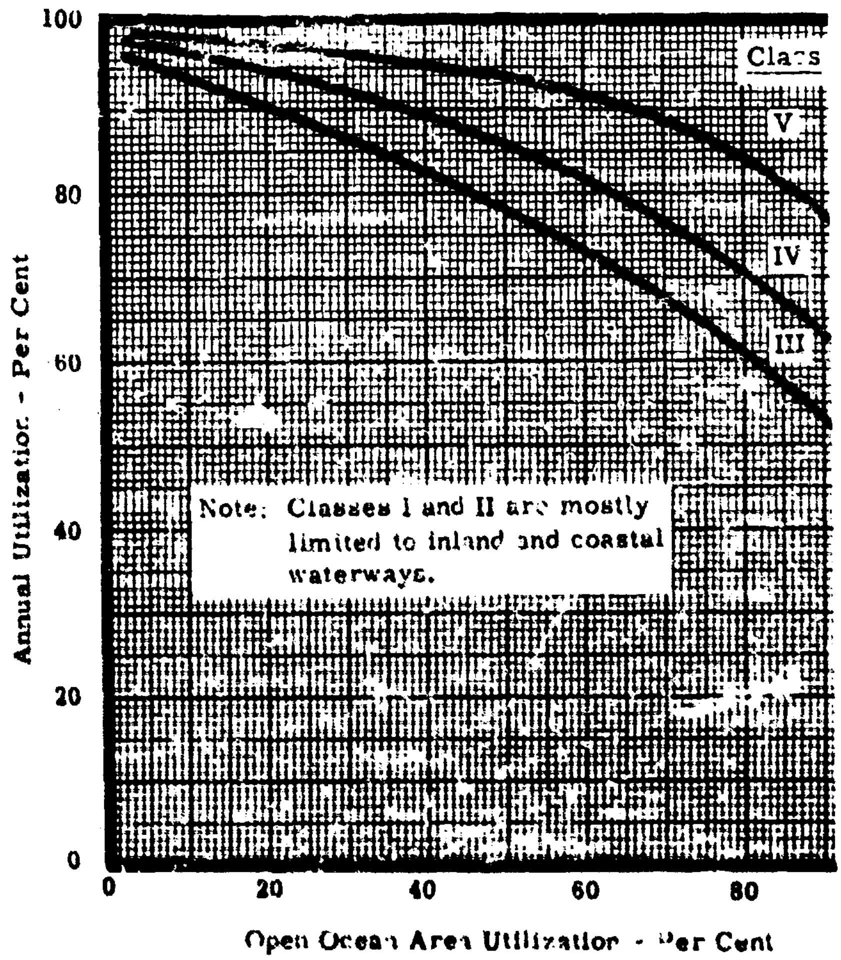


Figure 2

Marine GEM



4. OPERATIONAL FEATURES OF MILITARY GROUND EFFE ... MACHIN

(1) Visibility

As discussed in the Induced and Combat
Environment Sections, visibility, both from
vehicle, and of the vehicle by the enemy, pr ... nts
a significant problem. The extent of the pr ... em
depends mainly on the terrain over which the ... nicle
is operating.

In all terrains with loose surfaces, ar ... ver
water, means are required to reduce the exte ... to
which particles picked up by the air curtain ... e
projected in a vertical direction. Several
approaches are worthy of further investigati ... and
development; among these are particle deflec ... s,
which may result in some loss of performance ... nd
the application of recirculation to the lift ... stem,
which appears to offer greater promise since ... in-
creases the over-all vehicle efficiency as w ... as
reducing the particle projection problem.

For general visibility purposes, windsh ... d
cleaning devices, direct-visio window panel ... and
other features that are common practice in a ... raft
and ship design are directly applicable to (... .

DNES

Since the worst conditions of both c
defensive aspects of visibility arise in
condition, surface treatments can be util
provide a complete solution on a long-ter
where operational conditions permit. Har
stabilization of the terrain by chemical
means would provide essentially a partial
for regular operations.

(2) Maneuverability

Maneuverability becomes progressivel
tant as vehicles are considered for oper
amphibious and overland environments.

For the marine vehicle, operating p
large expanses of water, maneuverability
become a prime consideration until termi
are discussed. Here it would appear that
the marine configuration and design cond
vide a "displacement-craft" capability,
maneuverability can be attained.

In the amphibious role, a degree of
craft" maneuverability would be advantag
more demanding condition arises when the
cross the surf line and stop on a beach
area. A careful study of the handling a

Since the worst conditions of both offensive and defensive aspects of visibility arise in the hovering condition, surface treatments can be utilized to provide a complete solution on a long-term basis where operational conditions permit. Hardening and stabilization of the terrain by chemical or mechanical means would provide essentially a particle-free surface for regular operations.

(2) Maneuverability

Maneuverability becomes progressively more important as vehicles are considered for operation in marine, amphibious and overland environments.

For the marine vehicle, operating primarily in large expanses of water, maneuverability does not become a prime consideration until terminal operations are discussed. Here it would appear that by choosing the marine configuration and design conditions to provide a "displacement-craft" capability, the required maneuverability can be attained.

In the amphibious role, a degree of "displacement-craft" maneuverability would be advantageous, but a more demanding condition arises when the craft has to cross the surf line and stop on a beach in a limited area. A careful study of the handling and control

characteristics required for such a maneuver will probably indicate the desirability of utilizing skids, wheels, sea anchors, reversible pitch air propellers, or a number of other devices in order to provide this capability for stopping suddenly. In any event, the craft must be able to slow down to a suitable speed for negotiating land obstacles as soon as the beach is approached.

The overland vehicle presents the most severe maneuvering problem, since it must negotiate areas which have probably not been cleared with GEM operations in mind. The need to stop rapidly, to change direction and to accelerate quickly are all paramount to a successful overland GEM operation. The approach adopted by one British design group, that of providing a basic GEM design with a half-track system for use part of the time, may prove to be the most practical for the overland vehicle. Further consideration of maneuverability in overland operations is required.

(3) Navigation

The basic principle of operation of a GEM makes it particularly well suited, by contrast to normal surface vehicles, for travelling from point-to-point

rapidly with comparatively little regard for the terrain to be crossed. Since this implies that the GEM can operate in areas where routes have not been previously established or surveyed adequate navigation facilities are essential to their operation. In particular, equipment to detect the presence of obstructions along the intended route, such as trees, large outcrops of rock, banks, heavy surf conditions, and so on, will be required.

(4) <u>Accumulation of Surface Material, Snow and Ice</u>

During operations over surfaces that will permit the GEM downwash to dislodge particles, much material will be returned towards the machine and may collect on the machine. Prolonged operation will result in accumulation in all the crevices, intakes, and re-entrant contours of the machine, resulting in a severe servicing problem. If the environment is one of snow, ice or freezing rain and mist, then the collected material will build-up, adding to the gross weight of the machine, and impeding efficient operation of the lift system and engines. It is, therefore, essential that the machine be configured to avoid locations where accumulation can take place. In addition, adequate snow and ice removal equipment must be installed where the operational situation demands it.

This may consist of electrical, mechanical, thermal or pneumatic devices, as well as the use of chemical sprays on the surface.

5. SPECIAL FEATURES AND EQUIPMENT

(1) The following features and equipment are common to all vehicles in every class:

Heating and air-conditioning for crew and cargo compartments in Arctic or tropic areas.

Shock and vibration isolation throughout the structure.

Sand, dust and spray intake screens or deflectors over engine and lift system intakes.

Engine boost capability for tropical conditions.

(2) The following special features are common to marine and amphibious vehicles:

Cushion edges around outermost vehicle perimeter, for structural protection during loading and unloading at wharves or alongside ship.

Anti-corrosion treatment for the structure, the powerplants, and the lift system, to permit sustained operation in salt water areas and tropical areas.

Flotation capability for water handling, and for safety in the event of power failure.

Wheeled bottom for ground handling.

Strengthened bottom to resist impact with coral and rocks.

Hydrophobic treatment on beaching surfaces, such as skids, to provide long service life for these components.

(3) The following special features are common to amphibious and overland vehicles:

Retractable legs to support vehicle above rocky terrain, when power is shut down.

Erosion-resistant coatings in the lift and propulsion systems, particularly in the intake regions and on the first stage blades.

Power boost for jump capability rather than excessive installed power required for this capability.

(4) The following special features are required by overland vehicles:

Anti-corrosion treatment for tropical operations.

6. SUMMARY OF OPERATIONAL FEATURES

The 15 classes of vehicles, their required operating conditions, utility, special equipment and other features of interest, are summarized in Tables 20 and 21 following this page.

Table 20
Summary of Military GEM Characteristics

Type	Class	Size: Length ft.	Size: Width ft.	Operating Height Required by Surface: Normal	Operating Height Required by Surface: Max	% of Year Operation is Feasible	% of Land & Water Surface Vehicle Can be Used	Slope Capability Required	Surface Treatment Required before Operating Vehicle	Relative Vulnerability Similar to: Ship	Relative Vulnerability Similar to: Truck	Relative Vulnerability Similar to: Aircraft	Special Equipment Required	Relative Maintenance Level: Truck	Relative Maintenance Level: Aircraft	Transportability Possible by: Aircraft	Transportability Possible by: Ship
Marine	I	40	20	1	1.5	Year round	Coastal water and inland waterways	5-10%			x				x	x	x
	II	60	30	1.5	2.5	Year round		5-10%	GEM		x		** a,b,c,d,e,		x		x
	III	100	50	2.5	4	61	90% of ocean *	5-10%	beaching		x		f,g,h,i,j,k,		x		x
	IV	150	75	4	6	70	60% of ocean *	5-10%	ramps		x		l m n.		x		x
	V	200	100	6	10	94	80% of ocean *	5-17%			x				x		x
Amphibious	I	40	20	1.5	2.5	Year round	10% of beaches 10% inland	10%	none		x				x	x	x
	II	60	30	2	3	Year round	40% of beaches 25% inland	15%	none		x		a,b,c,d,e,		x		x
	III	80	40	3	5	Year round	70% of beaches 40% inland	15%	none		x		f,g,h,i,j,k,		x		x
	IV	100	53	3	5	Year round	70% of beaches 35% inland	15%	none		x		l,n,n		x		x
	V	[illegible]	65	4	6	Year round	53% of beaches 30% inland	15%	none		x				x		x
Overland	I	20	10	1	2	Year round	6% grassy plain only	15%	fill in ditches and bulldoze path		x				x	x	x
	II	40	20	1	4	Year round	18% of land mass	20-30%			x				x	x	x
	III	60	30	3	6	Year round	34% of land mass	30%			x		a,b,c,g,o,p		x		x
	IV	80	[illegible]	3	6	Year round	33% of land mass	30%	clear path		x				x		x
	V	100	50	3	6	Year round	20% of land mass	30%			x				x		x

* see also Figure 26

** see Special Equipment Listing, Table 21.

Table 2:

Special Features and Equipment

<table>
<tr><th>Overland</th><th>Amphibious</th><th>Marine</th></tr>
<tr><td colspan="3">a. Heating and air-conditioning for crew and cargo compartments.
b. Shock and vibration isolation throughout the structure
c. Sand, dust and spray screens or deflectors over engine and lift system intakes.
d. Engine boost capability for tropical conditions or jump capability.
e. Obstructions radar or equivalent.
f. De-icing for Arctic and Antarctic operations.</td></tr>
<tr><td>g. Anti-corrosion treatment for tropical operations.</td><td colspan="2" rowspan="2">h. Cushion edges around vehicle perimeter, for structural protection.
i. Anti-corrosion treatment, to permit sustained sea operations.
j. Flotation capability.
k. Wheeled bottom for ground handling.
l. Strengthened or protected undersurface to resist impact.
m. Hydrophobic treatment on beaching surfaces, to reduce friction and wear.
n. Clear-vision windshield.</td></tr>
<tr><td></td></tr>
<tr><td colspan="2">o. Retractable support legs for static support above rough terrain.
p. Erosion-resistant coatings in the lift and propulsion systems.</td><td></td></tr>
</table>

B I B L I O G R A P H Y

1. Berry, F.A., Jr., Bollay, E., Beers, Norman R., Handbook of Meteorology, pp. 994-995, New York, McGraw-Hill, 1945.

2. Bluh, Otto, Principles and Applications of Physics, London, England. Oliver and Boyd, 1955.

3. Cosmopolitan World Atlas, New York, Rand McNally & Company, 1958.

4. Critchfield, Howard J., General Climatology, pp. 165-244, Edgeworth Cliffs, N.J., Prentice-Hall, Inc., 1960.

5. Eshbach, Handbook of Engineering Fundamentals, John Wiley and Sons, Inc., April, 1957.

6. Geophysics Research Directorate, "Handbook of Geophysics for Air Force Designers," ARDC, U.S.A.F., Air Force Cambridge Research Center, 1st Edition, 1957.

7. Schonland, B.F.J., Atmospheric Electricity, Mattmen and Company, Ltd., 1953.

8. Trewartha, Glenn T., An Introduction to Climate, 3rd ed., pp. 223-395, New York, McGraw-Hill, 1954.

9. Van Rooy, M.P., (ed.), Meteorology of the Antarctic, Weather Bureau, Pretoria, South Africa, 1957.

10. Visher, Stephen S., Climatic Atlas of the United States, Cambridge, Massachusetts, Harvard University Press, 1954.

11. World Atlas, Encyclopaedia Britannica, Inc., Chicago, 1959.

12. Central Intelligence Agency, Military Geography, Chapter II, National Intelligence Survey (for country of interest). (Confidential)

13. U.S. Department of the Army, Field Manual 30-10, Terrain Intelligence, Washington, D.C., October 28, 1959.

14. U.S. Navy Hydrograph Office. Oceanographic Atlas of the Polar Seas. H.O. Pub No 705, Part I, Antarctic; Washington, D.C., 1957, and Part II, Arctic; Washington, D.C., 1958.

15. U.S. Navy, Marine Climatic Atlas of the World, Volume I, North Atlantic Ocean, NAVAER 50-1c-528, Washington, D.C., 1956.

16. U.S. Navy, Marine Climatic Atlas of the World, Volume II, North Pacific Ocean, NAVAER 50-1c-529, Washington, D.C., 1956.

17. U.S. Navy, Marine Climatic Atlas of the World, Volume III, Indian Ocean, NAVAER 50-1c-530, Washington, D.C., 1957.

18. U.S. Navy, Marine Climatic Atlas of the World, Volume IV, South Atlantic Ocean, NAVAER 50-1c-531, Washington, D.C., 1958.

19. U.S. Navy, Marine Climatic Atlas of the World, Volume V, South Pacific Ocean, NAVAER 50-1c-532, Washington, D.C., 1959.

20. U.S. Weather Bureau, Local Climatological Data (for Various Cities of the United States), Washington, D.C., 1960.

21. U.S. Weather Bureau, Summary of Hourly Observations, Climatography of the United States, Nos. 30-1 through 30-52, Washington, D.C., 1956.

22. U.S. Weather Bureau, and U.S. Navy Hydrographic Office, Climatological and Oceanographic Atlas for Mariners, Volume I, North Atlantic Ocean, Washington, D.C., August, 1959.

23. Boardman, F.D., Basic Principles of Radar with Particular Reference to Aircraft and Missile Applications, Journal of the Royal Aeronautical Society, October, 1959.

24. Field, R.L., Edwards, T.M., Kangas, P., and Pigman, G.L., "External Sound Levels of Aircraft," IAS Preprint No. 126, New York, N.Y., Institute of Aerospace Sciences, 1956.

25. Fielding, F.G., An Approach to the Operational Features Desirable in a Military Acceptable GEM, IAS Paper 61-70, New York, N.Y., Institute of Aerospace Sciences, January, 1961.

26. Ljungstrom, Olle, GEM Design Philosophy for an Over-water, Over-ice Vehicle, IAS Paper 61-47, New York, N.Y., Institute of Aerospace Sciences. January, 1961

27. Lloyd, P., Some Aspects of Engine Noise, Journal of the Royal Aeronautical Society, September, 1959.

28. Stanfelt, Harry, Jr., and Forchard, J. Everette, "Helicopter Noise, Its Evaluation and Treatment," American Helicopter Society, Seventeenth Annual National Forum, May, 1961.

29. Stanton-Jones, R., Some Design Problems of Hovercraft, IAS Paper 61-45, New York, N.Y. Institute of Aerospace Sciences, January, 1961.

30. Stirgwolt, Ted F., "Salt Water Ingestion by Gas Turbine Engines," American Helicopter Society, Seventeenth Annual Forum, May, 1961.

31. U.S.A.F. Aerospace Medical Center (ATC), Aeromedical Reviews--Aircraft Noise, Review 3-60, School of Aviation Medicine, Brooks Air Force Base, Texas, June, 1960.

32. Wosser, J.L., and Van Tuyl, A.J., A GEM for Amphibious Support, SAE Paper 270D, New York, N.Y., Society of Automotive Engineers, Inc., January, 1961.

33. Allison Division of General Motors Corporation, Progress Reports 1, 2, 3, and 4, "T-56 Foreign Object Damage Program."

34. Atlantic Research Corporation, "Investigation to Determine Buildup of a Static Electric Field Change in a Rolling Fluid Transporter," Contract No. DA-44-177-TC-461, September, 1959.

35. Austin, Kenneth A., and Votre, Louis S., Turbine Driven Amphibians--The New Trend in Fast Assault Craft, Lycoming Division, AVCO Corporation. February, 1961.

36. Bailey, H.P., "Climate of Coastal Regions," Natural Coastal Environments of the World. Prepared for Geography Branch, Office of Naval Research by the University of California at Los Angeles, 1960.

37. Bell Aerosystems Company, Ground Effect Machines Morphology Study, Buffalo, N.Y., January, 1961.

38. Bianchini, G.V., "T-56 Hail Impact and Ice Ingestion Tests," Allison Division of General Motors Corporation, September, 1956.

39. Booz · Allen Applied Research, Inc., The Ground Effect Machine, Technical Aspects-Operational Characteristics and Evaluation Parameters, Bethesda, Maryland, August, 1960.

40. Coordinating Research Council, Inc., Electrostatic Discharges in Aircraft Fuel Systems - Phase I, New York, N.Y., April, 1960.

41. Cornell Aeronautical Laboratory Inc., "Pocket Data for Human Factor Engineering," Report No. UB-1227-V-3, September, 1958.

42. Cornell Aeronautical Laboratory, Inc., Some Factors of Military Geography Affecting Mobile Army Combat Zone Transport Operations, Mobile Army Air Transport Study Phase II, Buffalo, N.Y., May, 1959. (Confidential)

43. The Garret Corporation, AiResearch Manufacturing Division, "Progress Report of U.S. Navy Contract No. Nonr 3024(00) GEM Propulsion System Study," Report No. AP-5017-R, June, 1960.

44. Hiller Aircraft Corporation, VTOL Downwash Impingement Study--Velocity Survey, TREC Technical Report 60-58 August, 1960.

45. Hiller Aircraft Corporation, VTOL Downwash Impingement Study -- Surface Erosion Tests, TREC Technical Report 60-67, October, 1960

46. Kuhn, Richard E., "An Investigation to Determine Conditions under Which Downwash from VTOL Aircraft will Start Surface Erosion from Various Types of Terrain," NASA TN D-56, September, 1959.

47. Logan, Richard F., The Central Namib Desert, South West Africa, Publication 758 of National Academy of Sciences, National Research Council, Prepared for Office of Naval Research by the University of California at Los Angeles 1960.

48. Lycoming Division, AVCO Corporation, "First Test Results. Lycoming's Sand and Dust Program for the T 53 Gas Turbine Engine," October, 1958.

49. Masters, H.W., "Water and Ice Ingestion Test of T 56 A-7 Gas Turbine Engines," Report No. 9 F 39, Allison Division of General Motors Corporation, August, 1959.

50. Mirabito, LCdr. John A., Notes on Antarctic Weather Analysis and Forecasting, NWRF 16-1260-038, Norfolk, Virginia, U.S. Navy Weather Research Facility, December, 1960.

51. National Fire Protection Association, "Static Electricity in Aircraft Operations and Maintenance," Boston, Massachusetts, May, 1960.

52. Pegg, R.J., Damage Incurred on a Tilt-Wing Multi-propeller VTOL/STOL Aircraft Operating Over a Level, Gravel-Covered Surface, NASA TN D-535, December, 1960.

53. Planning Research Corporation, A Classification System for Unprepared Landing Areas, Los Angeles, California, January, 1957.

54. Rayner, J.N., Temperature and Wind Frequency Tables for Eurasia, Meteorology Publications 18 and 20. Prepared for Headquarters, Quartermaster Research and Engineering Command by Arctic Meteorology Research Group, McGill University, Montreal, 1960.

55. Richards, E.J., Notes on the Noise of Ducted Fan Engines, Aeronautical Research Council Report 20,900, Great Britain, April, 1959.

56. Sommers, J., Jr., and Pate, Roger C. Bird Ingestion Tests of an Allison T-56 Turbine Engine, CAA Technical Development Report No. 312, May, 1957.

57. Syracuse University Research Institute, Interim Report on Infrared Detections, Physics Report 104-5, February, 1961.

58. Tunsic, R.J., Model T 56-A-1A Power Section, Sand and Dust Ingestion Test, Engineering Department Report No. 1269, Allison Division of General Motors Corporation, September, 1958.

59. Burkchart, M. D., Kipper, ...
Sea Conditions--North ... North Indian Ocean. Unp... 2-61, U.S. Hydrogra... Oceanography, Washing...

60. Ploetz, LCdr. John ..., USN, ... Handbook for Naval Air ... Navy Weather Central, Mo... (Mimeographed Internal I...)

61. U.S. Navy Hydrographic Offic... Oceanography, Sea Condi... Ocean. Unpublished Man... D.C., April, 19..0.

62. U.S. Navy Hydrographic Off... Oceanography. Unpubli... of the South Pacific, ... Indian ... Atlantic Oceans.

63. U.S. Navy Weather Research ... Planning Summary for ... During Operating Perioc ... 1960 (Mimeographed Int... Document).

64. U.S. Navy Weather Research F...lity... Report on the Meteorolog... Norfolk, Virginia, Augus... 19... (Mim... Internal Document).

65. Chief of Engineers, U.S. Army, ... Cross-Country Movement, ... 19...

66. VTOL Aircraft Downwash Impi... ...osium, Army Transportation Res... Virginia, December, 19...

67. Ridenour, Louis N., Radar ... Radiation Laborato... Book Company, In... 19...

Discussions were held ...
...ing agencies: U.S. Navy Hy... Weather Research Facility. ... U.S. Weather Bureau, Army M... Geology Branch of the U.S. ...